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QUALIFICATION TEST METHODS FOR  
HELICOPTER CARGO HANDLING SYSTEMS

David O. Adams

United Aircraft Corporation

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<p>The unreliability of some current cargo handling systems has resulted in the loss of expensive military equipment. Additionally, the unavailability of aircraft and the many maintenance man-hours on cargo handling systems have caused increased costs and mission aborts. The basic reason for this has been a lack of appreciation, by both the Army and the helicopter manufacturer, for the rigors of cargo helicopter operation. Southeast Asia experience has shown that rough handling and the combined effects of extreme environmental conditions and operational cycles are the leading causes of cargo handling system failures.</p> <p>The purpose of this report is to present cargo handling system qualification test methods which better represent actual field use and to systematize methods for demonstrating stated reliability requirements for these devices. Then, with realistic requirements to work to, both the design and the development processes should produce cargo handling systems with acceptable performance.</p> <p>The major conclusions are that: cargo hooks, cable, pendants, slings, nets, and tie-downs should undergo rough handling tests; present environmental test conditions are generally adequate but not properly applied. Environmental conditions should be applied simultaneously with endurance test conditions; test programs should be based on <u>a priori</u> reliability requirements, not on arbitrary margins and "ignorance factors;" and randomization and test acceleration methods may be used to produce more realistic and cost-effective programs.</p>			

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Cargo hook						
Cargo sling						
Cargo net						
Hoist cable						
Winch cable						

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This report was prepared by Sikorsky Aircraft under the terms of Contract DAAJ02-72-C-0037. It consists of methods and philosophy for the qualification test of helicopter cargo handling systems and components. The main body of the report is divided into three parts: Part I, General Test Methods, covers aspects of testing common to all cargo handling components and systems; Part II, Component Test Methods, describes test methods for all major types of cargo handling system components; Part III, System Test Methods, describes test methods for helicopter hoisting/winch-ing systems.

The object of this contractual effort was to analyze and define the minimum requirements for qualifying helicopter cargo handling systems and system components.

The test methods contained herein represent a thorough and comprehensive approach to the qualification of helicopter cargo handling systems and system components. However, it must be recognized that in addition to being thorough, they are also time consuming and costly. Nevertheless, it is believed that the increase in reliability of cargo missions and subsequent decrease in lost cargo will more than offset the increased cost of qualification testing.

Mr. Eugene A. Birocco, Military Operations Technology Division, served as the technical monitor for this program.

10

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QUALIFICATION TEST METHODS FOR  
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Final Report

Sikorsky Engineering Report No. SER-50795

By

David O. Adams

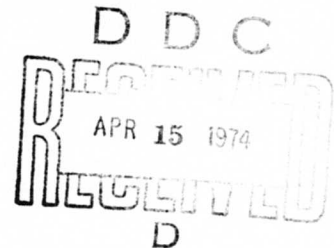
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## SUMMARY

The unreliability of some current cargo handling systems has resulted in the loss of expensive military equipment. Additionally, the unavailability of aircraft and the many maintenance man-hours on cargo handling systems have caused increased costs and mission aborts. The basic reason for this has been a lack of appreciation, by both the Army and the helicopter manufacturer, for the rigors of cargo helicopter operation. Southeast Asia experience has shown that rough handling and the combined effects of extreme environmental conditions and operational cycles are the leading causes of cargo handling system failures.

The purpose of this report is to present cargo handling system qualification test methods which better represent actual field use and to systematize methods for demonstrating stated reliability requirements for these devices. Then, with realistic requirements to work to, both the design and the development processes should produce cargo handling systems with acceptable performance.

The methods presented here are based on: a survey of Sikorsky helicopter cargo handling system reliability data; a study of existing cargo handling component military and federal specifications; a survey of current cargo handling system qualification test methods and subsequent results on Sikorsky equipment; meetings with several cargo handling system subcontractors; and the experience and judgments of Sikorsky engineers, pilots, and technicians.

The major conclusions are that: cargo hooks, cable, pendants, slings, nets, and tie-downs should undergo rough handling tests; present environmental test conditions are generally adequate but not properly applied. Environmental conditions should be applied simultaneously with endurance test conditions; test programs should be based on a priori reliability requirements, not on arbitrary margins and "ignorance factors;" and randomization and test acceleration methods may be used to produce more realistic and cost-effective programs.

## FOREWORD

This study was conducted under Contract DAAJ02-72-C-0037, DA Task 1F162203AA3303. Technical administrator for the project was Mr. G. Birocco of the Eustis Directorate of USAAMRDL. All work was accomplished between February and November 1972.

The task manager for the project at Sikorsky was Mr. D. O. Adams, who was assisted by E. J. Conklin, R. S. Goldman, W. Huebner, W. Huly, H. L. Kearney, R. B. Stewart, and W. F. Throp.

Three cargo handling system subcontractors also provided assistance: Mr. R. Walsh at The Breeze Corp, Union, N. J.; Mr. L. Stivitsts at Bergen Wire Rope Co., Lodi, N.J.; and Mr. R. Huber of Eastern Rotorcraft Corp., Doylestown, Pa.

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## INTRODUCTION

Helicopter cargo handling systems have become considerably more common, larger, and more complex with the advent of the large utility and cargo helicopters in recent years. In addition, cargo handling systems are now incorporated on almost all military helicopters of all sizes, reflecting the wide variety of missions commonly assigned to these machines. As a result, failures and problems with cargo handling systems are increasingly more visible, and it has become apparent, especially in view of Southeast Asia experience, that significant improvements in reliability and availability are necessary.

One means toward that end is to improve the design requirements and test methods used to qualify cargo handling systems for service. Although it is difficult to exactly simulate, in testing, the conditions encountered in field use of a component or system, it has been recognized that currently used test methods fall short of this simulation. The methods recommended here are an attempt to simulate the effects of operational use as closely as practical and to promote a better understanding of the true nature of the problem of qualification testing of a cargo handling system.

This is a general qualification test specification for all common helicopter cargo handling systems. In order to be applicable to the entire range of helicopters and missions, from LOH to HLH, these test requirements must be presented in the form of guidelines by which specific test plans are generated. That is, the detail specification for the cargo handling system in question must completely specify the loading spectrum, loading rates, functional requirements, design life, environmental conditions and specific reliability requirements. With these parameters available, the test plan is formulated through the use of the three major parts of this report: Part 1 - General Test Methods, Part 2 - Component Test Methods, and Part 3 - System Test Methods.

Part 1, General Test Methods, covers aspects of testing common to all cargo handling components and systems. Included in this section are environmental test requirements, test design considerations, reliability testing methods, and test acceleration methods. Reference is made in the other parts of the report to the applicable paragraphs of Part 1.

Part 2, Component Test Methods, describes test methods for all major types of cargo handling system components. Some of the components in this section do not receive a full test program, since they are better tested as part of a complete system. In this case, the methods of Part 3 take this into account. Conversely, some components, such as rigging points, pods, sheaves, fixed hooks, and tie-downs, are not included in systems-level testing since adequacy of function is better shown at the component level.

Part 3, System Test Methods, describes test methods for helicopter hoisting/winch systems. At this level, the interaction of components is investigated and performance, endurance and reliability data are obtained. Included in this section are lifting hoist/winch systems, positioning hoist systems, and multiple-point hoisting systems.

## TRADE-OFF STUDY

This section discusses the projected benefit - a measurable decrease in failure rates - resulting from the adoption of the qualification test methods described in this report. Additionally, the projected increased costs of components designed to meet these new requirements and the additional costs of the expanded test programs themselves are discussed. Finally, an example is given of a recent application of these test concepts to a helicopter cargo hoist program and the resulting improvement in reliability in field use when compared to a similar hoist which was designed and tested using the "old" test criteria.

The trade-off of benefits against costs is presented in Table I. It shows that, although the costs of components may increase by as much as 25%, and the costs of testing may increase by as much as 80%, a decrease in the field failure rate of as much as 70% can result. Since a failure of a cargo handling system or component may have far-reaching consequences, the increased costs may be easily offset in all but low-production or low-utilization programs.

The data presented in Table I was derived as follows:

CURRENT FAILURE RATE - This is derived directly from the failure data given in Appendix II on Sikorsky helicopters in military service, from failures experienced by commercial operators of Sikorsky helicopters in cargo missions, and from "Description of External Cargo Equipment Failures on Navy and Marine Helicopters 1968 - 1972, Job Number 2D39-BB-02." These sources provide a good, representative view of cargo helicopter operations, incorporating data from several years, from several sizes and types of helicopters, and from military and civil use of cargo helicopters.

PROJECTED INCREASE IN COMPONENT COSTS - Components designed to meet the new requirements will necessarily be more costly than those designed using current requirements. The estimate of the increase is based on increased design effort to provide for the product's meeting the new test requirements and the increase in manufacturing costs due to the additional design features.

PROJECTED INCREASE IN NONRECURRING TESTING COSTS - Testing costs using the new test methods are compared for each component with current test costs. The estimate includes a comparative evaluation of man-hours, test equipment, and number of test specimens required.

TABLE I. TRADE-OFF ESTIMATES OF TEST COSTS AND BENEFITS					
Component or System	Current Failure Rate (Failures per 10 <sup>6</sup> Flt Hours)	Projected Increase in Component Costs (%)	Projected Increase in Nonrecurring Testing Costs (%)	Projected Failure Rate (Failures per 10 <sup>6</sup> Flt Hours)	Projected Decrease in Failure Rate (%)
Controls	450	*	10	300	30
Power Systems	640	Low	25	320	50
Hoists and Winches	340	5	50	100	70
Load Isolators	750	*	40	150	80
Rigging Points	Low	0-5	0	Very Low	50
Emergency Releases	1000	10	30	300	70
Cables	1000	10	60	400	60
Pendants	3000	20	80	600	80
Hooks	590	5	50	320	45
Slings	10,000	25	80	2000	80
Nets	*	*	80	*	50
Containers, Pods	*	10	30	*	50
Rollers and Sheaves	Low	0-5	10	Very Low	60
Cargo Restraints	*	*	70	*	50
*Insufficient Data Available					

PROJECTED FAILURE RATE - This value is derived directly from the Current Failure Rate data. Each type of failure was examined and a determination was made as to which failure types would be eliminated or greatly reduced through the redesign resulting from the use of the recommended test program. The failures remaining determine the projected failure rate.

A specific example of the benefits involved in using the new test methods is found in the single-point hoist systems designed for the CH-54A and CH-54B helicopters.

#### CH-54A CARGO HOIST

- . Design Goals:
  - 15,000 lb capacity, raise, hold or lower
  - 50 feet per minute cable speed
  - Environment tolerance
  - 4000 cycles between overhaul
- . Actual Performance:
  - 15,000 lb raise or lower, 18,800 lb hold
  - 40 to 45 feet per minute cable speed
  - Some environmental and operational problems

#### CH-54B CARGO HOIST

- . Design Goals:
  - 25,000 lb capacity, raise, hold or lower
  - 50 feet per minute cable speed
  - Environment tolerance
  - 4000 cycles between overhaul
- . Actual Performance
  - Same as design goals - hoist has actually raised, lowered, and held loads of up to 35,000 lb. Very few environmental or operational problems.

The cost and weight of the CH-54B hoist are slightly higher than those of the CH-54A hoist, and this is primarily due to increased performance requirements. The most significant factor accounting for the difference in actual performance is the design specification requirement for the CH-54B hoist calling for environmental/endurance testing such as recommended in this report. As a result, consideration was given to these requirements very early in the basic design phase, and the finished product went through the expanded test program with very few problems, in spite of concurrently applied environmental and endurance test conditions. In service, the CH-54B hoist meets or exceeds all design requirements, including environment tolerance, and has a very low failure rate.

## 1. GENERAL TEST METHODS

This section presents test methods that are common to the various types of cargo handling components and systems. Included are: environmental test methods, test design considerations, reliability test methods, and test acceleration methods.

### 1.1 ENVIRONMENTAL TEST METHODS

#### 1.1.1 Philosophy of Tests

The following environments are considered:

- Vibration
- Sand and Dust
- Salt Fog
- Extreme Temperature
- Humidity
- Fungus Resistance
- Sunshine
- Rain
- Altitude
- Ice Accumulation
- Fluid Damage Resistance

Failures of aircraft components due to environments, both natural and induced, are too common, especially in the light of the fact that these same components have been "qualified" in accordance with some kind of environmental test program. The problem does not appear to lie with the type and range of environmental tests currently used but rather with the method of application. Specifically, in current practice such as in MIL-STD-810B, "Environmental Test Methods," environments are not allowed to interact with endurance effects during the test program. It is apparent that this interaction can be very significant, the most prominent example being the sand and dust test. In this case, the operation of the test article during environmental testing could induce significant amounts of dust to enter critical seals and mechanisms which would otherwise be unaffected.

A further consideration is that, in current test programs, possible environmental effects are sometimes reduced by "cleaning" procedures. In the sand and dust test, for example, the brushing away of excess sand from the test article is allowed prior to an operational test. This cleaning procedure is done infrequently in many field situations, and the same applies to washing, lubricating, and touching up the paint on an aircraft's components. These normal maintenance chores lose their importance in combat zones and we cannot depend on their being done.

Vibration testing is another area where a change is recommended. In addition to the test program currently used, the test article should be subjected to a prolonged period of excitation at the pre-dominant aircraft frequencies and amplitudes, whether it is a resonant condition or not. This test condition is more realistic than the MIL-STD-810B "resonant dwell" test and is more likely to turn up the real potential problem areas.

Many different endurance/environmental effects and simple environmental effects are possible, depending partly on the component or system being tested. The test program for each component or system includes recommendations as to which environments are to be applied, at what point in the test, and the manner of application. When the environmental conditions are to be applied in a randomized test plan, Section 1.2.2.2 provides guidelines.

Sections 1.1.2.1 through 1.1.2.6 cover the environmental tests which are generally applied to the test specimens prior to endurance testing. These environments are not considered to have a significant effect dependent on the simultaneous operation of the test article. However, if the environment does have a deleterious effect, the subsequent endurance test will serve to bring out this effect further.

Sections 1.1.2.7 through 1.1.2.12 cover the environmental tests which are generally applied during endurance testing. The interaction between environment and operation is considered to be significant.

### 1.1.2 Methods

The following methods apply to cargo handling systems in general and are to be used as specified in Part 2, Component Test Methods, and Part 3, System Test Methods.

#### 1.1.2.1 Vibration Tests

Two test procedures are used, performed sequentially. The first determines, and is dependent on, the resonance characteristics of the test article itself. The second is dependent on the aircraft application, designed to uncover any problems due to long-term exposure to airframe vibration.

##### A. Standard Tests

Use MIL-STD-810B, Method 514.1, Category C, Curve M - "Equipment Installed in Helicopters, Without Vibration Isolators." This widely used specification consists of a resonance search, resonance dwell, and cycling at frequencies between 5 and 500 cps and amplitudes up to 5g. The duration of this test is 3 hours, at the completion of which the test article is inspected and functionally checked.

##### B. Additional Tests

In addition to the standard tests, one of the tests described below shall be conducted. Use test (1) if the vibration environment to which the test article will be subjected is known, i.e., frequency(ies), amplitude(s), direction(s) and phasing. This may be determined by design analysis or, if the application is on an existing aircraft type, by flight test measurements. Use test (2) if the vibration environment is undefined or if a general qualification is required.

(1) Known Vibration Environment

Duration - Subject the test article to the known vibration environment for a time equal to the time-between-overhauls of the test article, or the expected flight life of the aircraft, as specified in the detail specification.

Operation - The test article shall be subjected to a functional test, unloaded, at least ten times in equally spaced increments during the length of the vibration test.

(2) Undefined Vibration Environment

Duration - The test article shall be subjected to the vibration environment for a total time equal to the time-between-overhauls of the test article, or the expected flight life of the aircraft, as specified in the detail specification. One-third of the test shall be conducted with the vibration excitation in the vertical direction, one-third in the lateral direction, and one-third in the longitudinal direction.

Mounting - The test article shall be mounted in its normal "stowed" position for cruise flight, and it shall be excited by the test fixture in either the vertical, lateral, or longitudinal direction as required.

Frequency - The frequency of the applied vibration shall be the predominant excitation frequency found on the type of helicopter for which the test article is intended. For general applications, the frequency shall be 15 cps.

Amplitude - The amplitude of the applied vibration shall be that specified in MIL-STD-810B, Method 514.1, Category C, Curve M at the excitation frequency specified above.

Operation - The test article shall be subjected to no-load functional tests for ten cycles in equally spaced increments during the length of the vibration test.

#### 1.1.2.2 Fungus Resistance Tests

Due to the extreme complexity of the fungus problem and because of the great variety and number of fungus types, no general test program can practically verify resistance to worldwide fungus exposure. The following three considerations should be followed:

- Incorporate a fungicide in the formulation of all nonmetals and protective finishes used in the component.
- Obtain fresh samples of all fungi from the area of intended use. Perform the fungus resistance test of MIL-STD-810B using these fungi. The difficulty and expense involved here is recognized; however, there is no other way of positively verifying fungus resistance.
- If applicable fresh fungi samples are not available, one species from each of the four groups listed below shall be applied in accordance with MIL-STD-810B:

Group I	Chaetomium Globosum	6205
	Myrothecium Verrucaria	9095
Group II	Memononiella Echinata	9597
	Aspergillus Niger	6275
Group III	Aspergillus Flavus	10836
	Aspergillus Terreus	10690
Group IV	Penicillium Citrinum	9849
	Penicillium Ochrochloron	9112

Samples of the material used in the construction of the test article may be used in lieu of the test article itself. The failure criterion shall be: sufficient degradation in characteristics to affect the performance of the test article. If the degradation in characteristics is questionable and a design review is not undertaken, each complete test article shall be subjected to this test prior to endurance testing.

#### 1.1.2.3 Sunshine Tests

No test method presently in use matches exactly the accelerated aging process of natural sunshine. In addition to the problem of duplicating the radiation of the sun with an artificial light source, the length of exposure is also difficult to define. The exposure time depends on several variables: the latitude of the area of the component's use, the percentage of time that the component is exposed each day, the season(s) of use, and the component's design life.

The method recommended here is to expose the component (or a material sample) to natural sunlight at the same latitude of intended use, for a period determined by the detail specification requirements. This is recognized to be, in many cases, an impractical approach, but it is the only method known to realistically qualify aircraft components for sunshine exposure.

When the above cannot be done, an accelerated test using artificial light is sufficient. Procedure I of MIL-STD-810B, Method 505, shall be used, except that the specified radiant energy rate of 100 to 120 watts per square foot shall be changed to 120 to 140 watts per square foot in order to accelerate the test, and the test shall be of 300 hours duration for each year of design life. The temperature is maintained at 113°F.

Except in the case of nonmetallic structural members, this test may be performed on samples of the materials used in the construction of the test article in lieu of the test article itself. Nonmetallic structural member test articles shall be sunshine tested as complete units prior to endurance testing since sunshine is known to have a deleterious effect on the strength of many of these items. The test may be deleted entirely when the material and any protective coatings are known to be immune to sunlight degradation.

The failure criterion shall be: sufficient degradation in characteristics to affect the operation or performance of the test article. If the degradation in characteristics is questionable and a design change is not made, each complete test article shall be subjected to the test prior to endurance testing.

#### 1.1.2.4 Altitude Tests

Procedure II of MIL-STD-810B, Method 500, shall be used. This specification includes a reduction in temperature to -65°F as well as a change in pressure to the level applicable for operation of the test article. However, there is no provision in that specification for high-altitude transport, and this is incorporated by adding the following provisions to the MIL-STD-810B procedure:

- The test article shall be operated during the periods of temperature and pressure change up to the operational limits specified in the detail specification.
- At the conclusion of the operational test, step 5, the chamber altitude shall be increased to the maximum altitude to which the test article may be subjected during shipment in fixed-wing aircraft, as specified in the detail specification. This altitude shall be maintained for 6 hours.
- The chamber altitude shall then be reduced to the operational altitude and the test sequence resumed by repeating step 4.

This test may be deleted entirely if the design of the test article does not incorporate any altitude-sensitive devices.

#### 1.1.2.5 Fluid Damage Resistance Tests

The following procedure shall be used to ascertain the tolerance of the test article to the damaging effects of fluids which it may encounter during its operational life. The fluids to be applied should be specified in the detail specification according to the projected aircraft environment for the test article. As a minimum, the following fluids should be considered:

- aircraft fuel, such as JP-5
- transmission lube oil, such as MIL-L-7808
- cleaning fluids, such as Varsol
- hydraulic oil, such as MIL-H-5606
- solvents, such as methyl ethyl ketone (MEK)
- sea water (if no salt spray test is done)

Each test specimen shall be exposed, prior to endurance testing, for 3 hours each in all test fluids. Exposure may be accomplished by complete immersion in the test fluid; or if the size of the test article dictates, the test fluid may be sprayed on at least once every 30 minutes, taking care to apply fluid from all angles and to thoroughly wet all parts of the test article. At the end of the exposure period, the test article shall be allowed to air dry for 20 hours without any wiping or cleaning. The test article may then be cleaned by any adequate means and visually inspected for damage.

If any damage or change is evident due to the action of the fluid, the component shall be rejected, unless it can be shown that an immersion of 30 hours duration, followed by an air dry of 200 hours, causes no damage which could affect the operation or performance of the test article.

In addition to the above test performed prior to endurance testing, it is recommended that hoist system endurance tests incorporate a fluid damage resistance test, since there is often an interaction with simultaneous operation of the hoist.

#### 1.1.2.6 Ice Accumulation Test

The purpose of this test is to demonstrate proper operation of the test article when all parts are coated with ice resulting from condensation and freezing. This test is not intended to qualify the test article for operation after extended flight in icing conditions since the ice is of a different character. In addition, the latter requirement is covered in airframe icing tests.

In most cases, the ice accumulation test is performed prior to endurance testing. However, if the test article incorporates many moving parts and the effect of the ice may change with environmental/time effects, the ice accumulation test should be included in the endurance test environments.

The test article shall be maintained at -65°F in the test chamber until the temperature stabilizes. The test article shall be exposed as quickly as possible to 100°F and 90% relative humidity and condensation allowed to form. When all frost on the test article has melted, the article shall be returned to the test chamber at -65°F until temperature stabilizes. A functional test at this temperature and inspection for abnormalities shall be performed.

#### 1.1.2.7 Sand and Dust Test

The procedures of MIL-STD-810B, Method 510, shall be used, with the following changes:

- The composition of the sand and dust shall be 97 to 99% by weight  $\text{SiO}_2$  of angular structure, and shall have equal homogeneous portions by weight of sand and dust containing minimum and maximum particle sizes as follows:

Sand - particle size 0.01 to 1.00 mm

Dust - particle size 0.0001 to 0.01 mm

- Accumulations of dust may be removed only during scheduled overhauls or scheduled cleanings, or by the natural action of the test article.
- The test article shall be operated throughout the test.

This test is run in three sequential parts. In the first part, the test chamber is maintained at 73°F, the dust concentration is 0.3 gram per cubic foot, and the air velocity is 1750 feet per minute. The total duration of this part is 6 hours, or, when applied in a randomized endurance test of 4 blocks according to Section 1.2.2.2, 1-1/2 hours per block.

In the second part, the dust feed is stopped and the chamber is maintained at 145°F for a total duration of 16 hours, or 4 blocks of 4 hours each.

In the third part, the chamber temperature is maintained at 145°F, the dust concentration is 0.3 gram per cubic foot, and the air velocity is 1750 feet per minute. The total duration of this part is 6 hours, or 4 blocks of 1-1/2 hours each.

The length of the block sand and dust test then works out to be 7 hours, and the block is applied in the endurance test at each of the 4 points determined by the procedures of section 1.2.2.2.

#### 1.1.2.8 Salt Spray Test

The procedures of MIL-STD-810B, Method 509, shall be used, with the following changes:

- Accumulations of salt and corrosion may be removed only during scheduled overhauls or scheduled cleanings, or by the natural action of the test article.
- The test article shall be operated throughout the test.

The duration of the salt spray test is 48 hours, or, when applied in a randomized endurance test of 4 blocks according to section 1.2.2.2, 12 hours per block.

#### 1.1.2.9 Extreme Temperature Tests

##### A. High Temperature

Procedure II of MIL-STD-810B, Method 501, shall be used, with the following changes:

- The operating temperature shall be 140°F and the storage temperature shall be 160°F instead of the 120°F and 154°F specified.
- The test article shall be operated at all times during the 140°F portion of the exposure, and during all heating and cooling periods below 140°F.
- Four complete temperature cycles shall be run instead of three.

This test consists of a 6-hour exposure at 140°F while the test article is operated, a 1-hour change to 160°F, a 4-hour soak at 160°F, and a 1-hour change to 140°F. If the four 12-hour cycles are to be performed without interruption, a 1-hour exposure at 140°F while the test article is operated is added at the end of the final cycle. Total test duration is thus 49 hours. If the test program is randomized according to Section 1.2.2.2, each 12-hour cycle plus 1 hour at 140°F while the test article is operated is performed once in each of 4 blocks for a total test duration of 52 hours.

B. Low Temperature

The procedure of MIL-STD-810B, Method 502, shall be used, with the following requirements:

- Storage temperature shall be -80°F, maintained for at least 24 hours total.
- Operating temperature shall be -65°F, and the test article shall be operated at this temperature for a total of 4 hours.
- The test article shall be operated during all cooling and warming periods above -65°F.

This test consists of lowering the test chamber temperature to -80°F and maintaining that temperature for at least 24 hours total, or for a block time of at least 6 hours. The chamber is then warmed to -65°F, and the test article is operated for 4 hours total or a block time of 1 hour. The test article is then warmed to ambient temperature while operating. The total duration is in excess of 28 hours, or if run in a randomized block cycle, 4 cycles of 7 hours each.

1.1.2.10 Temperature Shock Tests

The procedure of MIL-STD-810B, Method 503, shall be used, with the following changes:

- The test article shall be operated at least once during each of the stabilized hot, cold, and ambient conditions.

- The test article shall be operated during all warming periods of the test.
- One test chamber may be used provided that the chamber ambient temperature can be changed within 15 minutes.

This test begins with a 4-hour soak at 160°F, during which time the test article is operated at least once. It is then transferred to a cold chamber at -65°F within 5 minutes, or the temperature in the same chamber is changed within 15 minutes to -65°F. The chamber is maintained at this temperature for at least 4 hours, during which time the specimen is operated at least once. The transfer is then made back to a 160°F chamber within 5 minutes, or within 15 minutes in the same chamber while the test article is operated. The test chamber is returned to ambient temperature after 1 hour at 160°F, during which time the test article is operated at least once.

This 9-hour cycle is repeated 4 times, once in each environmental block.

#### 1.1.2.11 Humidity Test

Procedure I of MIL-STD-810B, Method 507, shall be used, with the following changes:

- The test article shall preferably be operated at all times throughout the test, and at least 5 times during each test period.
- At no time shall moisture be removed except by the natural action of the test article itself.
- The test shall consist of twelve 24-hour cycles instead of ten.

This test cycle begins with a gradual change from ambient to 95% humidity and 160°F over a period of 2 hours and then stabilized at this condition for 6 hours. Then, while maintaining at least 85% humidity, the chamber temperature is reduced in 16 hours to 82°F. This 24-hour cycle is repeated 12 times, or if the endurance test is randomized according with Section 1.2.2.2, 3 times per environmental block.

#### 1.1.2.12 Rain Tests

The procedures of MIL-STD-810B, Method 506, shall be used, with the following changes:

- The total duration of the rain exposure shall be at least 16 hours (thirty-two 30-minute cycles).
- The test article shall be operated throughout the tests.

The rain cycle consists of 5 in./hr for 10 minutes, 12 in./hr for 5 minutes, and 5 in./hr for 15 minutes, during which time a wind velocity of 40 mph is maintained. If the test is divided into 4 randomized blocks according to Section 1.2.2.2, each block shall consist of eight 30-minute cycles.

### 1.2 ENDURANCE/ENVIRONMENTAL TEST DESIGN

#### 1.2.1 Philosophy of Tests

It is not the function of this document to present a complete course in experimental test design. However, those methods and analyses which pertain especially to cargo handling systems, or which could be unfamiliar to many readers, are included here. This section covers identification of variables, randomization of test conditions, reliability test methods, and test acceleration methods.

It is recognized that, even with accelerated testing, these test design and reliability methods require much longer test programs than is now the current practice. The basic reason for this is that, since reliability requirements for non-safety-of-flight components such as cargo handling equipment have never been carefully delineated, it was not realized how deficient the test programs were in showing reliability. In many cases, only one sample was tested at unaccelerated conditions, from which no reliability conclusions could legitimately be made.

The new approach, then, is that the customer carefully defines his reliability requirements and the contractor performs tests of sufficient scope to demonstrate that his components meet these requirements. The higher cost of this approach can be justified since it is very likely that costly redesign and retrofit as well as maintenance costs will be reduced, aircraft availability will be increased, and less cargo will be lost.

## 1.2.2 Methods and Procedures

### 1.2.2.1 Identification of Variables

As in any properly run test program, all the variables having a significant effect on the result must be identified. In endurance test work it is usually straightforward - the dependent variable being cycles (or time) to failure and the independent variables being load, environments, and operational characteristics such as hook releases, hoist braking cycles, sling bend radius, etc.

Consideration should then be given to the less obvious but controllable endurance test variables such as time of day, test operator, downtime between cycles, shutdowns, etc. Unless it can be proven that these variables have no effect, they should be randomized along with the primary variables according to the following section.

There are, of course, variables which are uncontrollable, such as ambient weather conditions, or unknown variables which may affect the result. By running the test in a random sequence, these variables appear as scatter in the results. If the scatter is large, the test engineer knows that some primary variable was not included in the test design, and he may choose to identify it by further investigation.

#### 1.2.2.2 Randomization

Randomization of test conditions, i.e., the application of the various levels of each independent variable in a random order, provides four key benefits:

- Important unknown variables show themselves in the form of large scatter.
- The minor effects of uncontrolled variables also appear as scatter.
- Test results may be expressed in terms of only one variable instead of many. For example, when loads and environments are applied in random order, test failures are related only to endurance cycles, regardless of the exact load or environmental condition at failure.
- The best simulation of general service use is obtained. Unless the life spectrum and/or mission spectrum is highly specialized and carefully defined, the assumption of a random load/environment spectrum is the most logical one to make. It is unlikely that any general-purpose helicopter would spend its entire life performing the same mission under the same conditions.

An ideally randomized test program is one where, for each cycle, each independent variable is changed to a different, randomly chosen level. In most cases this is not a practical approach, since some variables are difficult and expensive to change on each cycle. The endurance test programs recommended in this study include environmental conditions run simultaneously and hence fall into this category. The technique of "block randomization" is used to obtain a logical compromise.

A typical cargo handling system test program has at least load and environments as the independent variables, with cycles-to-failure as the dependent variable. There are, of course, additional independent variables which depend on the specific function of the system. Of these, the environments are usually the most difficult to change. The first step in designing a random test plan is to divide the applications of each variable into the smallest practical increments. In the case of the load variable, the increment might be 200 cycles if the load were a concrete weight of over 25,000 pounds, since the load is difficult to change, but the increment might be one cycle if the load were applied by an automated, programmed hydraulic loading system. In the case of environments, a division into four increments is recommended as a practical compromise; that is, the specified total duration of each of the required environmental test conditions is divided by 4. A listing of environmental conditions which are likely to be applied during endurance testing, depending on individual test requirements, is shown in Table II. The table indicates the total duration of each test, as required by the applicable sections of 1.1, Environmental Test Methods, and also shows the duration of each of the "block" applications.

The next step is to arrange the independent variables into test blocks, starting with the basic "one-quarter size" environmental block. Each variable is then arranged in sub-blocks within this basic block so that a balanced test plan results. There are many acceptable ways of accomplishing this, the only real criteria being that each variable is applied the same number of times and that the plan is balanced. This is illustrated in the example below.

Example:

A hoist is to be endurance tested for 4000 cycles. Four different loads are to be used and two lifting conditions are imposed - normal with a built-in load misalignment, causing a side-sway motion. In addition, the cargo hook is to be remotely released after each cycle, 10% of these releases being air drops. The environments to be applied during the test are: sand and dust, salt spray, extreme temperature, temperature shock, humidity, and ice accumulation. The life spectrum (applied cycles) is as follows:

LIFE SPECTRUM

Type of Lift	Load, Lb			
	10,000	15,000	20,000	25,000
Normal	720	1,080	1,080	720
Side Sway	80	120	120	80

Total: 4000 cycles

TABLE II. ENDURANCE ENVIRONMENTAL TESTS

Section Number	Test	Total Duration (hr)	Block Duration (hr)
1.1.2.7	Sand and Dust	28	7*
1.1.2.8	Salt Spray	48	12
1.1.2.9.A	High Temperature	48	12*
1.1.2.9.B	Low Temperature	28	7*
1.1.2.10	Temperature Shock	36	9**
1.1.2.11	Humidity	288	72*
1.1.2.12	Rain	16	4*
1.1.2.6	Ice Accumulation	**	**
<p>* This environmental condition is varied in a cycle specified in the applicable part of Section 1.1.2.</p> <p>** This environmental condition consists of a single cycle applied in the block according to the applicable part of Section 1.1.2.</p>			

Since a test of this type involves changing weights, the load blocks should be kept fairly large; but since the smallest number of total cycles for any condition is 80, at least these blocks must be only 20 cycles (80 divided by the 4 environmental blocks). Two more conditions are 120 cycles, or 30 in each environmental block. The remaining conditions can be kept above 100 cycles and arranged into a 1000-cycle block as follows:

TEST BLOCK SPECTRUM

	Load, Lb					
	10,000	15,000		20,000		25,000
Normal	180 <sub>1</sub>	135 <sub>2</sub>	135 <sub>3</sub>	135 <sub>4</sub>	135 <sub>5</sub>	180 <sub>6</sub>
Side Swav	20 <sub>7</sub>	30 <sub>8</sub>		30 <sub>9</sub>		20 <sub>10</sub>

Total: 1000 cycles

This is the basic test block which, combined with environments and hook releases, is applied four times. As shown, each of the load blocks is sequentially assigned a number, 1 through 10. The order of application of these 10 test conditions is then randomized; i.e., the numbers 1 through 10 are arranged in a random order by some acceptable means -- cards, dice, or random number tables. For use in this example, consider the order so obtained to be 7, 3, 8, 10, 6, 4, 1, 5, 9, 2.

The question still remains as to when and in what order the six environmental conditions are to be applied. Note that some of these require the endurance test to be interrupted for application of the condition and a complete functional test. Others are applied while the hoist is cycling. In either case, a point in the endurance test must be identified for each environment. This is done by selecting randomly 6 of the 10 test conditions; for example, 4, 9, 5, 6, 3, 1. Now each environmental condition is assigned, in turn, in the order originally stated, to one of these load conditions. Sand and dust are applied at condition 4, salt spray at condition 9, etc. At this point it may be necessary to make minor changes to make the test more practical. It may be impossible, for instance, to finish the salt spray test during condition 9, which is only 30 cycles. But since condition 2, which follows 9 in the random order, has no environments, the salt spray test can be extended into condition 2.

Finally, the air-drop hook releases are placed in the endurance test at randomly selected points. This is one variable that can be "changed" every cycle. One possible way to do this would be to randomly select 10 numbers from 1 to 100 and to use this to determine which cycles incorporate air-drop releases. This selection of 10 numbers can be repeated every 100 cycles without adverse effect.

The test plan developed above for the first 1,000-cycle block can be summarized as follows:

TABLE III. EXAMPLE TEST SEQUENCE

Test Condition No.	Load (lb)	Number of Cycles	Lift Condition	Environment
7	10,000	20	Side Sway	Ambient
3	15,000	135	Normal	Humidity
8	15,000	30	Side Sway	Ambient
10	25,000	20	Side Sway	Ambient
6	25,000	180	Normal	Temp. Shock
4	20,000	135	Normal	Sand & Dust
1	10,000	180	Normal	Ice Accum.
5	20,000	135	Normal	Extreme Temp.
9	20,000	30	Side Sway	Salt Spray
2	15,000	135	Normal	

This same process would now be applied to each of the three remaining 1,000-cycle test blocks, deriving a different random order for each.

Two considerations may now be apparent as a result of this example:

- A failure early in the program, especially during the first 1,000 cycles, cannot be said to be related to only test cycles since there may be some bias due to the unbalanced application of the test conditions.
- If the test article is likely to fail during an environmental test condition, it is often better to apply these conditions at the beginning of each block. This sacrifices some of the advantages of randomization, but may save considerable test time.

### 1.2.2.3 Reliability Test Methods

Reliability can be defined as the probability of a device's performing its purpose adequately for the period of time intended under the operating conditions encountered. It is, however, much easier to define reliability than to demonstrate it in a test program of reasonable scope. As seen in the following sections, even moderate reliability requirements lead to test programs of impractical size, especially when each test article is an expensive item. The following alternatives should be considered:

- Reduce the demonstrated reliability requirement
- Reduce the required confidence in the results
- Accelerate the test to shorten the duration

The reliability analysis problem can be divided into two distinct areas: "wearout" and "chance failure." The mathematical techniques used in the two types of analysis are quite different.

Wearout criteria are used when there is only one cycle-dependent, nonrepairable mode of failure. Structural failure due to fatigue is the best example of this, although any major, nonrepairable, cycle-dependent failure should be classified as wearout.

The chance failure criteria will be used when the test item is complex and several different, repairable failure modes are possible. These failures occur at random intervals, but the expected failure rate over a long period of time is a constant. Wearout failures of minor components are included in chance failures; in fact, wearout failures probably contribute to the chance failure rate more than the true one-of-a-kind random failure. In addition, wearout usually aggravates the conditions which cause random failures. One precaution must be taken: test durations must not be so short that the short-term wearout failures cannot occur.

In cases where both wearout and chance failures must be considered in the same component, both criteria are applied and the longer of the two test programs is run.

The reader is assumed to have access to basic statistics, including normal, student's, and chi-squared distributions. Another distribution, the log normal, is often used, and this is presented in Appendix I. Much of the following can be found in References 2 and 3.

#### A. Wearout Failure Testing

##### (1) Definitions

- M - Sample Mean
- S - Sample Standard Deviation
- T - Target Life or Target Breaking Strength From Detail Spec.
- K - Standard Deviation Factor
- n - Number of Samples
- R - Reliability
- Y - Confidence Level
- $M_A$  - Actual Mean of the Population, Unknown
- $\sigma$  - Actual Standard Deviation, Unknown
- $M_L$  - Sample Mean, Log-Normal Distribution
- $S_L$  - Sample Standard Deviation, Log-Normal Distribution

## (2) General Case of Wearout Reliability

Two different approaches to wearout reliability testing can be used. Both use the same analysis and both are equally valid:

- Show, with  $\gamma$  % confidence, that  $R\%$  of the population represented by the test article(s) will have a life greater than the design life when operated under aircraft spectrum conditions.

or

- Show, with  $\gamma$  % confidence, that  $R\%$  of the population represented by the test article(s) will have a breaking strength greater than the design limit load at all times during their design lives.

These two test programs may be summarized as follows:

- Run the test(s) at aircraft spectrum loads, rates, and environments until a failure occurs.

or

- After completing an aircraft spectrum loading test of duration equal to the design life, determine the breaking strength of the test article(s).

Note that both test programs produce a distribution of data - a distribution of lives in one case and a distribution of breaking strengths in the other. It can be seen that most components are better suited to one approach than the other. Cable and slings, for example, which have only one mode of wearout failure - breakage - can be "strength" tested with a considerable savings in time. Hoists, on the other hand, have several modes of wearout failure and are more "life" oriented.

In either case, the distribution of data is "normal" or, especially with life data, "log-normal." When in doubt, the use of the log-normal distribution is recommended. A description of the log-normal distribution is presented in Appendix I.

If it were possible to take an infinite number of data points, the reliability could simply be shown as in Figure 1.

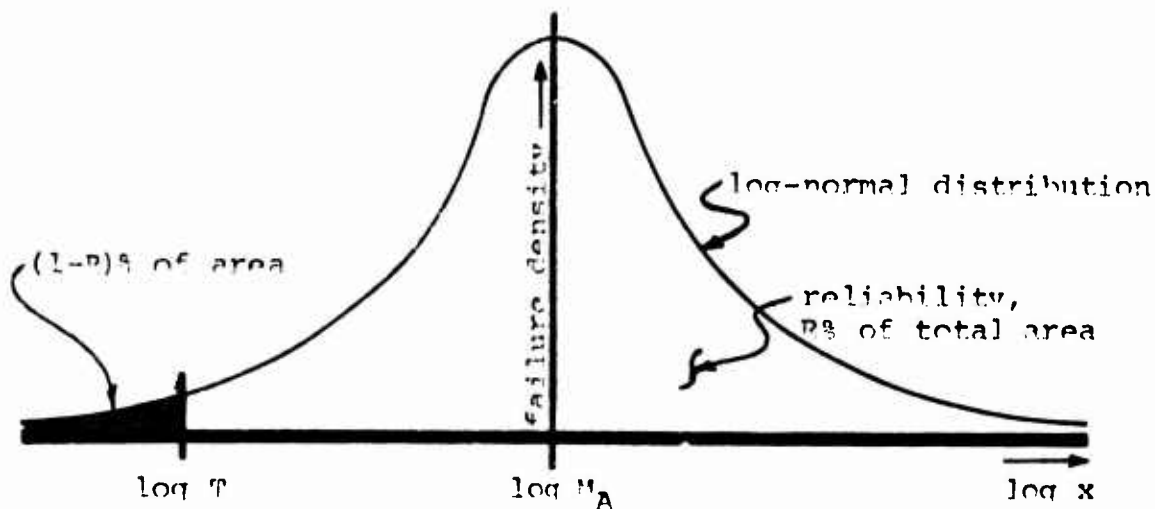


Figure 1. Illustration of Reliability Terms.

The parameter  $x$  may be either "time to failure" or "residual ultimate strength." The reliability shown is the probability that any data point  $x$  will exceed the target value  $T$ .

It should now be apparent why a distribution of test results is required, exceeding the normal life or the normal loading of the test article, in order to obtain data points. It is impossible to obtain an exact representation of the population and therefore impossible to obtain an exact value of the reliability of the population, but if a sample distribution is available, we can estimate the reliability with a specified level of confidence.

The reliability requirement can now be mathematically stated:

Normal Distribution:  $M - T \geq KS$

Log-Normal Distribution:  $\text{Log } M_L - \text{Log } T \geq KS$

where K is the "standard deviation factor" (the number of standard deviations that the measured mean value must exceed the target value in order to show reliability R with confidence Y for the population).

K depends only on n and Y and contains the uncertainty on both the mean M and the distribution standard deviation S.

In this general case, K may be found from Hald's equation:

$$K = \frac{K_R + K_Q \sqrt{\frac{1}{n} \left[ 1 - \frac{K_Q^2}{2(n-1)} \right] + \frac{K_R^2}{2(n-1)}}}{1 - \frac{K_Q^2}{2(n-1)}}$$

where  $K_R$  is the number of standard deviations on a normal distribution required to encompass R% of the total area, single tail, and  $K_Q$  is the number of standard deviations on a normal distribution required to encompass Y% of the total area, single tail.

TABLE IV. HALD'S EQUATION PARAMETERS	
$\gamma$ or R	$K_Q$ or $K_R$
50	0
60	0.255
70	0.525
75	0.675
80	0.84
85	1.04
90	1.282
95	1.645
97.5	1.960
98	2.055
99	2.326
99.5	2.576
99.9	3.09
99.99	3.719
99.999	4.265
99.9999	4.7

Hald's equation is represented in Figures 2 ( $\gamma = .90$ ) and 3 ( $\gamma = .95$ ).

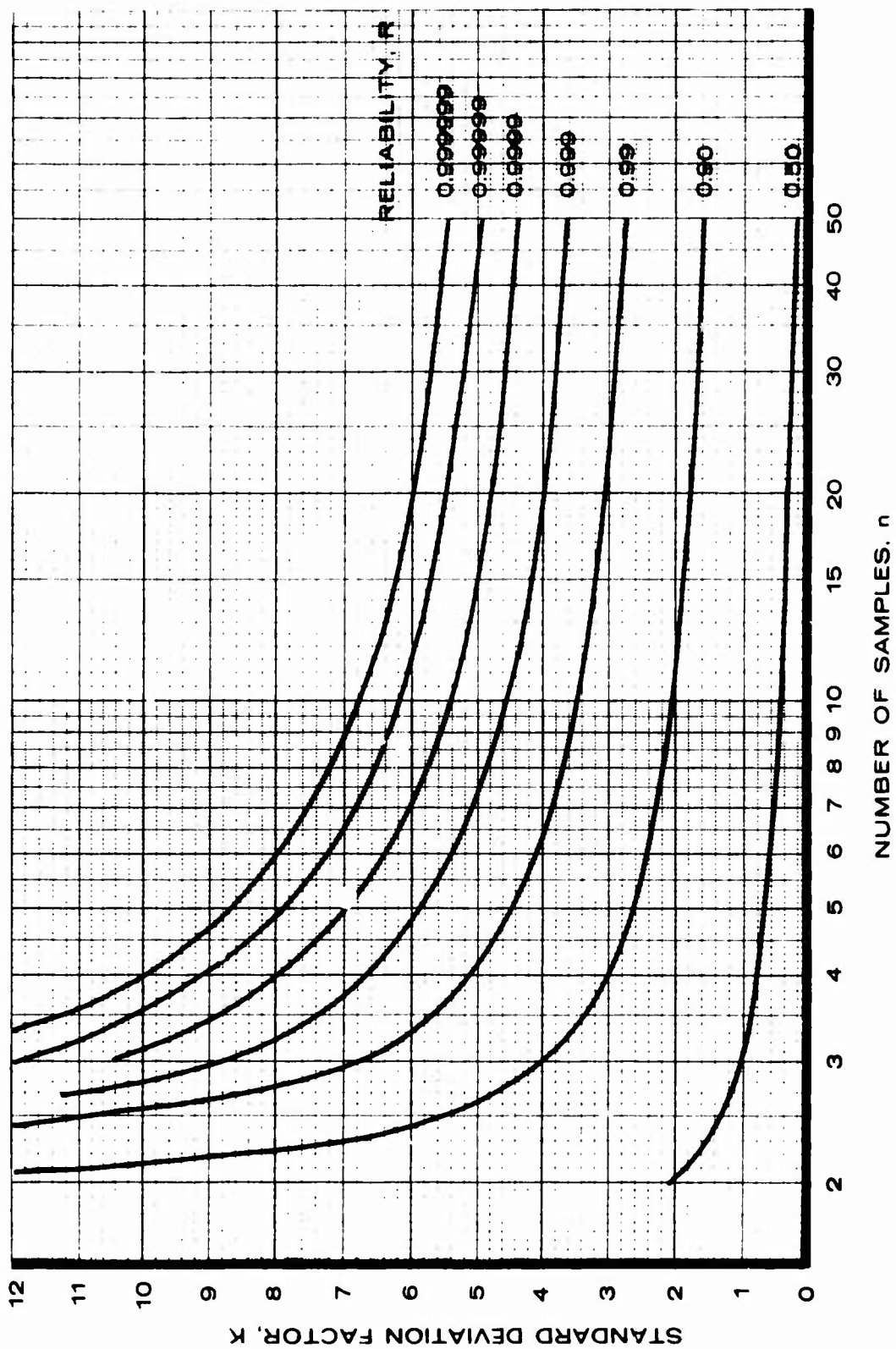


Figure 2. Reliability Curves, Unknown Variance, Confidence Level 90%.

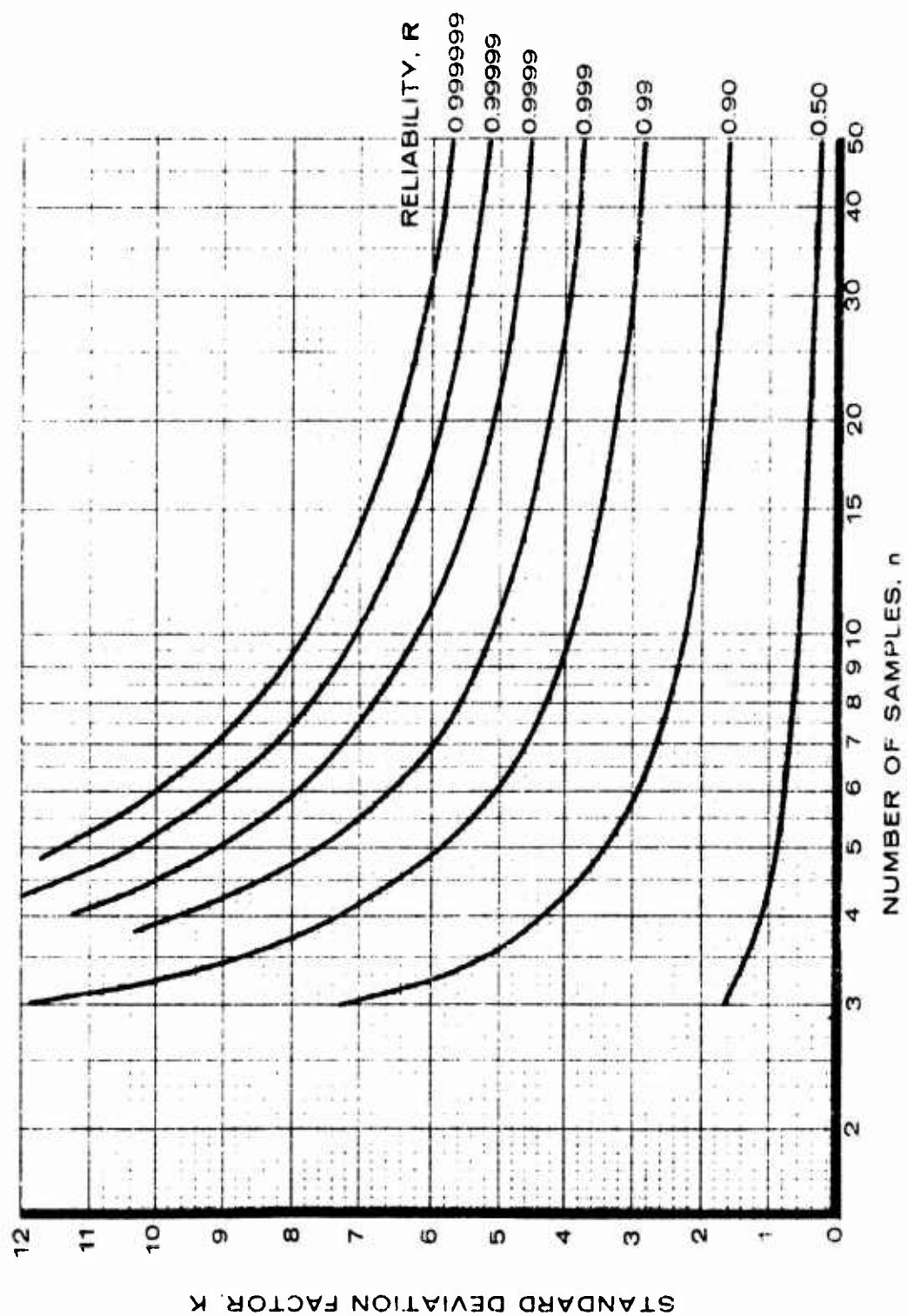


Figure 3. Reliability Curves, Unknown Variance, Confidence Level 95%.

### Example (1)

Determine the number of samples required to show a reliability against primary structural failure of 99% over a life of 5000 cycles, with 90% confidence. The life test approach is chosen, and the designer predicts that M will be at least 40,000 cycles and that S will be less than 10,000 cycles.

To proceed, the conversion to log coordinates is made. First, although it is known to be untrue,  $M_L$  is assumed to be equal to M. Then

$$\text{Log } M_L = \text{Log } 40,000 = 4.602$$

Next it is assumed that the stated S is equal to  $S_L$ , so that

$$S_L = \frac{\text{Log } M_L}{M_L - S_L} = \frac{\text{Log } 40000}{40000 - 30000} = \text{Log } 1.33$$

$$\text{or } S_L = 0.124$$

$$\text{Also, } \text{Log } T = \text{Log } 5000 = 3.699$$

Then, stating the reliability requirement,

$$\text{Log } M - \text{Log } T \geq KS$$

$$\text{or } 4.602 - 3.699 \geq K (.124)$$

$$K \leq 7.27$$

From Figure 2 (  $\gamma = .90$  ) at  $K = 7.27$ ,

$$n = 2.3; \text{ use 3 samples}$$

Note: If the data were assumed to be normally distributed instead of log-normal, the analysis would be

$$M - T \geq KS \text{ or } 40000 - 50000 \geq 10000K$$

$$K \leq 3.5$$

From Figure 2 (  $\gamma = .90$ ) at  $K = 3.5$ ,

$n = 3.3$ ; use 4 samples

Hence, it is seen that the use of what is usually the correct distribution results in a shorter test program.

During the running of the test, the designer's predictions on  $M$  and  $S$  are checked and the reliability is computed. The test may be stopped if the required reliability is verified early. If, on the other hand, at the completion of the planned test, the reliability requirement was not met, either more testing is required to reduce the uncertainty or a design review must be undertaken. We can see that although a design is actually quite adequate, if it has only a small margin of overdesign, many test samples may be needed to verify the reliability within the prescribed confidence level.

If the first test specimen in the above example fails at 52,400 cycles and the second fails at 36,800 cycles, it can be shown that the test may be terminated when the third specimen reaches 20,200 cycles. To verify this:

$$\left. \begin{array}{l} \text{Log } 52,400 = 4.719 \\ \text{Log } 36,800 = 4.566 \\ \text{Log } 20,200 = 4.304 \end{array} \right\} \begin{array}{l} \text{Log } M_L = 4.530 \\ \text{or } M_L = 33,900 \end{array}$$

$$\text{and } S_L = .210$$

Now, using  $\log M - \log T \geq KS$

and  $K = 3.96$  from Figure 2 at  $n = 3$ ,

$$4.530 - 3.699 = 0.831 \geq 3.96(.210) = 0.831$$

The stated reliability requirement is verified even though the mean is lower and the deviation higher than predicted (counting the terminated test), primarily because the standard deviation factor,  $K$ , is reduced considerably when 3 specimens are used rather than the theoretical 2.3 specimens.

### (3) Wearout Reliability When S Is Known

As illustrated in example (1), a long test program results when the only statistical information on the test article is gained from the test itself. The general method of the preceding section is therefore used when no statistical data is available on the test article or on closely related components.

In some cases, however, a fairly accurate estimate on S can be made based on experience with similar hardware. Because of the great many factors involved, a general listing cannot be made.

It is emphasized that since the uncertainty in the standard deviation is by far the largest contributor to the overall uncertainty, this method should be used only when the standard deviation can be substantiated with applicable test experience. A careful distinction is made between this and a "guess" as to what the S is. It is assumed in the following that S is based on 30 or more samples.

When S is known, the standard deviation factor, K, contains only the uncertainty on the mean of the distribution, which still depends on n and  $\gamma$ .

The range of variation on M is given by the student's distribution, t:

$$\text{Lower Limit on } M = M - t \left[ \frac{S}{\sqrt{n}} \right]$$

where t is tabulated against n and  $\gamma$ , the confidence level.

K, then, is found by adding the error on M to  $K_R$ , the factor which contains the reliability information.

$$K = K_R + \frac{t}{\sqrt{n}}$$

The reliability requirement is still

$$\begin{array}{ll} M - T \geq KS & \text{Normal} \\ \text{or } \log M - \log T \geq KS & \text{Log Normal} \end{array}$$

K for this case is presented in Figures 4 (  $\gamma = .90$  ) and 5 (  $\gamma = .95$  ).

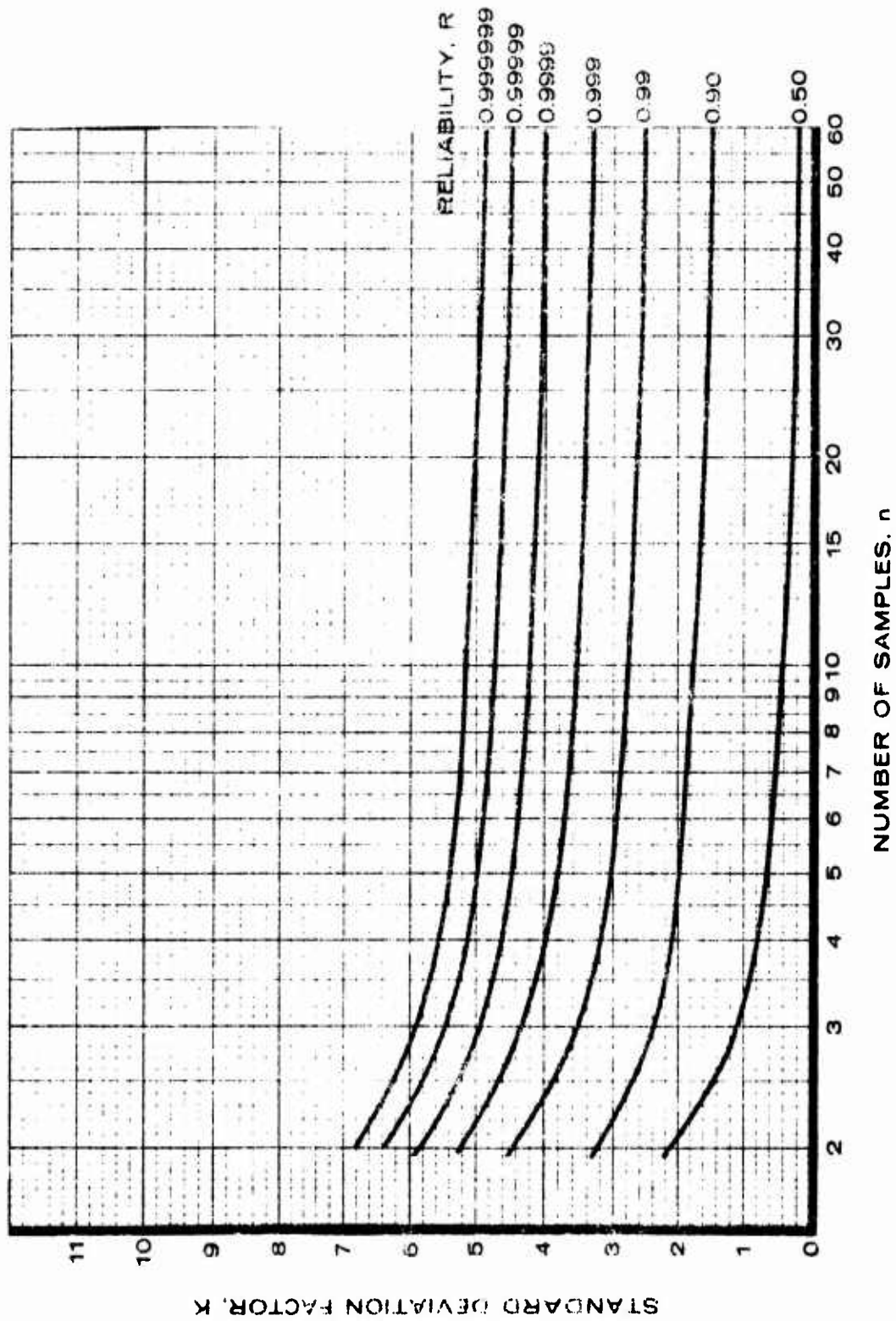


Figure 4. Reliability Curves, Known Variance, Confidence Level 90%.

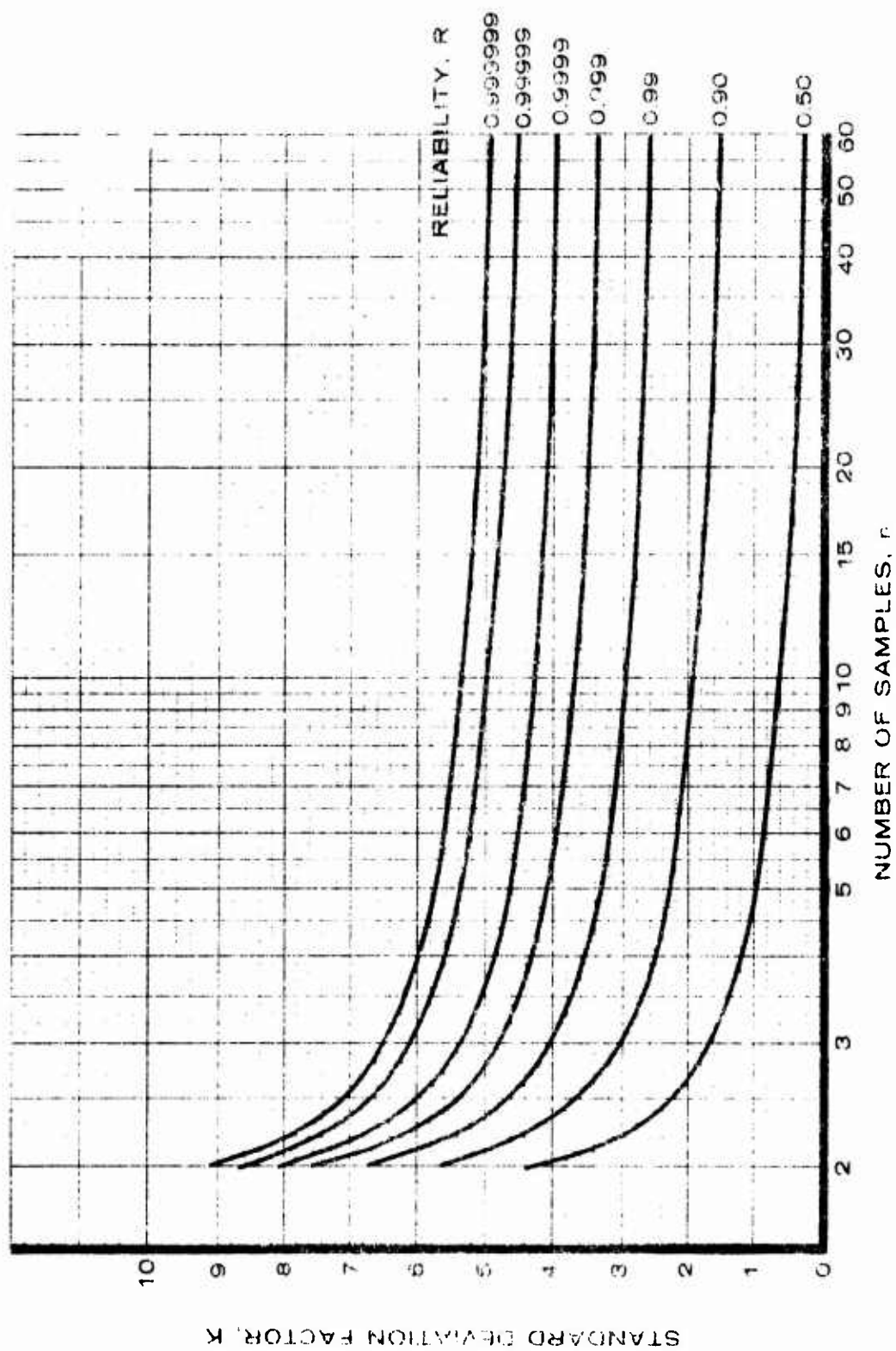


Figure 5. Reliability Curves, Known Variance, Confidence Level 95%.

### Example (2)

Using the same requirements as in example (1):  $R = 99\%$ ,  $T = 5000$  cycles,  $\gamma = 90\%$ , predicted  $M = 40,000$  cycles. In addition, suppose from previous tests that  $S$  were known to be 25% of the mean, or 10,000 cycles.

As in Example (1), the required  $K$  is found to be 7.27. In Figure 4 ( $\gamma = .90$ ) at  $K = 7.27$ ,

$$n < 2 \text{ (} n = 1 \text{ is undefined)}$$

Therefore, use 2 specimens.

Again, as the test progresses, the reliability is checked. If the first specimen fails at 52,400 cycles, then the test may be terminated when the second specimen reaches only 3500 cycles. To verify this,

$$\begin{array}{ll} \text{Log } 52,400 = 4.719 & \text{Log } M_L = 4.130 \\ \text{Log } 3,500 = 3.541 & M_L = 13,500 \end{array}$$

The "known"  $S_L$  is used: 0.124.

Then, using  $K = 3.50$  from Fig. 4 at  $n = 2$ ,

$$4.130 - 3.699 = .431 \geq (0.124)(3.50) = .434$$

Practically, of course, the test of only 3500 cycles on the second sample when the first sample went 52,400 cycles is unnecessary. Statistical rigor requires the second sample, but when one specimen has exceeded the life requirement by a factor of ten and the second test does not have to exceed the life requirement, it may be deleted.

In this example, 52,400 cycles were run on one sample, while in example (1), 109,400 cycles were required on three samples when  $S$  was not "known."

## B. Chance Failure Testing

### (1) Definitions

M or MTBF - Mean Time Between Failures

$M_T$  - Target MTBF, From Detail Spec.

$M_A$  - Actual MTBF, Unknown

$M_M$  - Measured MTBF, An Estimate of  $M_A$

n - Number of Samples (No. of Test Articles)

f - Number of Failures

T - Total Operating Time

$\lambda$  - Failure Rate,  $\lambda = 1/M$

$\gamma$  - Confidence Level

$\alpha$  -  $1 - \gamma$

$\chi^2$  - Chi Squared (A Statistical Distribution)

### (2) Reliability and MTBF

In the chance failure case, the reliability follows the well-known exponential formula:

$$R = e^{-\lambda t} = e^{-t/M}$$

Although this calculation is important, it is often omitted in specifications and only the MTBF is used. MTBFs vary considerably with the function of the system, but for mission-oriented devices such as cargo handling systems, an MTBF requirement of 1500 flight-hours is often specified. This figure results in a reliability which is low by safety-of-flight standards and is probably unacceptable for nonrepairable failures.

Safety-of-flight failures and non-repairable failures should then be considered as wearout failures, which involves a different analysis technique, as outlined in section (1). As noted previously, however, chance failures are primarily wearout related, but involve enough variables as to appear random. Since wearout is involved, the acceleration methods of section 1.2.2.4 apply to chance failure testing as well as to wearout failure testing.

### (3) The Chi-Squared Distribution for MTBF

It can be shown that the quantity

$$2f \frac{M_M}{M_A}$$

follows the statistical distribution known as the "chi-squared" distribution which is illustrated below in Figure 6.

The chi-squared distribution extends from zero to positive infinity and can be found tabulated in any set of statistical tables.

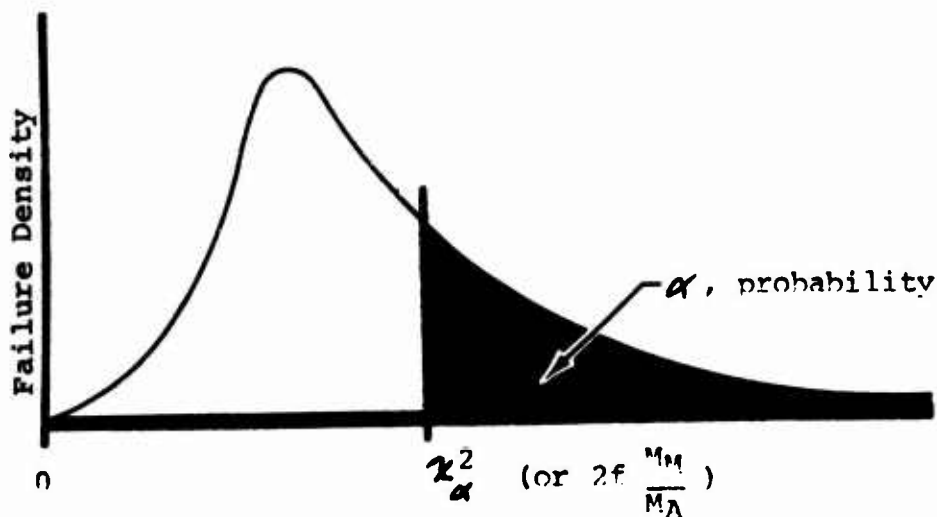


Figure 6. Chi-Squared Distribution.

In this case, the chi-squared distribution is used with  $2f$  degrees of freedom when the test from which the estimate  $M_M$  was obtained was terminated as the  $f^{\text{th}} M$  failure occurred.

The statistics are tabulated as values of  $\chi^2$  for which the area (probability) to their right under the distribution, with given degrees of freedom, is equal to  $\alpha$ . Some tables use the area to the left, and care must be taken to convert to the right convention used in this development.

The probability is  $\alpha$  that  $2f M_M/M_A$  is greater than  $\chi^2_{\alpha, 2f}$ .

Further, the probability is  $1-\alpha$  that  $2f M_M/M_A$  is less than  $\chi^2_{\alpha, 2f}$ , or

$$2f M_M/M_A \leq \chi^2_{\alpha, 2f} \quad (\text{Probability } 1-\alpha)$$

$$\text{or } M_A \geq (2f M_M) / (\chi^2_{\alpha, 2f}) \quad \text{or}$$

$$M_A \geq (2T) / (\chi^2_{1-\gamma, 2f})$$

with:

Probability  $1-\alpha$   
or confidence  $\gamma$   
where  $\gamma = 1-\alpha$  &  $T = fM_M$

The equation above is a probabilistic expression of the value of the unknown true MTBF in terms of the known failures and the confidence level on the result.

#### (4) Test Requirement

We wish to be able to show, with confidence  $\gamma$ , that  $M_A$  exceeds or equals  $M_T$ , through a test program that yields  $M_M$ .

This requirement is met if

$$(2f M_M) / (\chi^2_{1-\gamma, 2f}) \geq M_T \text{ since}$$

$$M_A \geq (2f M_M) / (\chi^2_{1-\gamma, 2f})$$

or, rewriting,

$$M_M \geq (M_T/2f) \left[ \chi^2_{1-\gamma, 2f} \right] \quad \text{Confidence } \gamma$$

$$\text{or } T \geq (M_T/2) \left[ \chi^2_{1-\gamma, 2f} \right] \quad \text{Confidence } \gamma$$

This equation gives the minimum test time in terms of the confidence level, number of failures, and the required MTBF. This equation may be used to predict the test time required if an estimate of the failure rate can be made, or to check the adequacy of existing test results.

Figure 7 is a representation of the test requirement in the form

$$M_M \geq K M_T$$

where  $K = (\chi^2_{1-\gamma, 2f}) / 2f$  (The "MTBF Margin Factor")

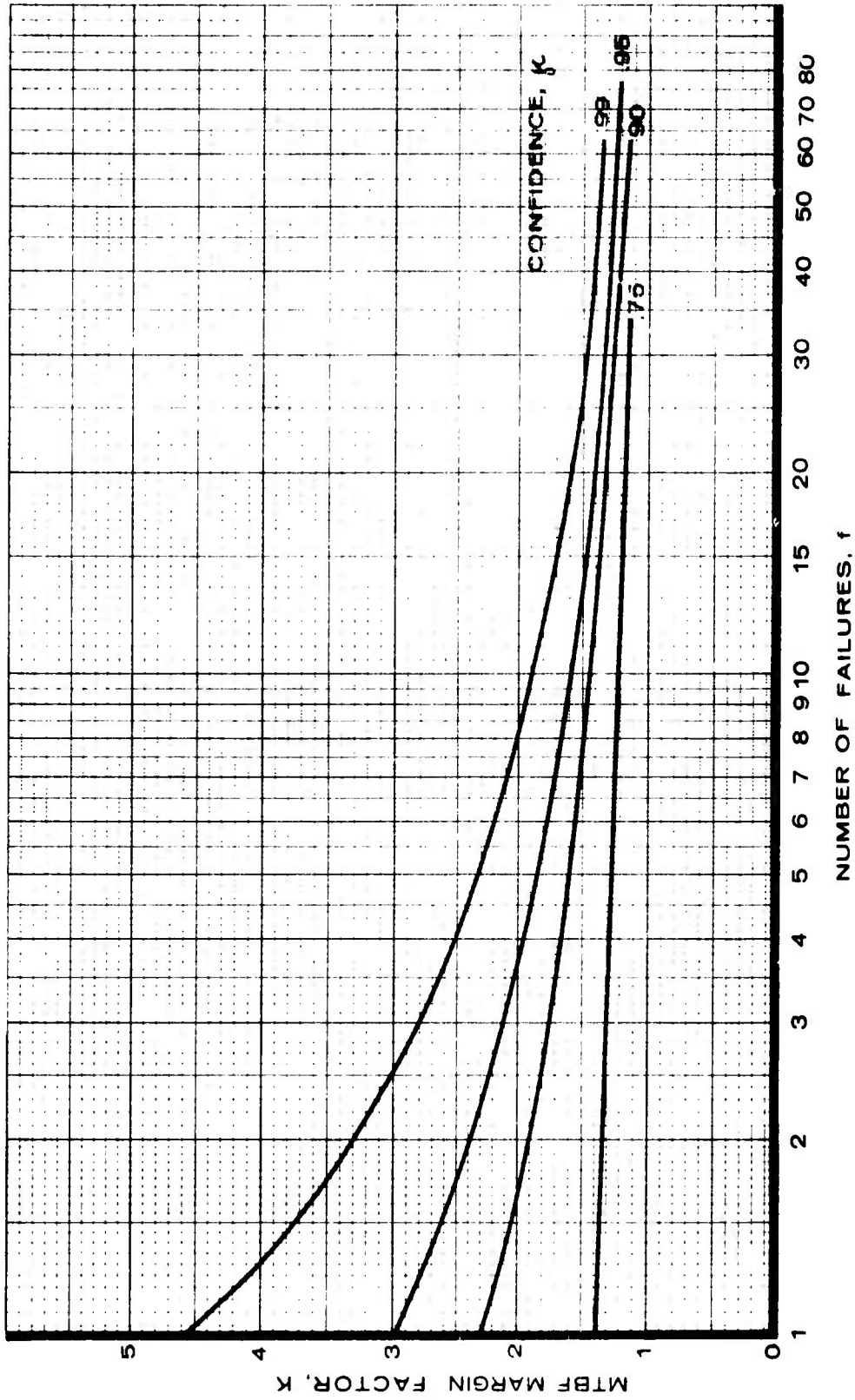


Figure 7. Chance Failure Curves.

(5) Examples

- The Single-Failure Case

$f = 1$ . Let  $\gamma = .90$ .

Then, since  $\chi^2_{.10,2} = 4.61$  from a tabulation of the chi-squared distribution,

$$T \geq M_T/2 (4.61) = 2.3 M_T$$

I.e., the target MTBF can be verified in a test of duration  $2.3 M_T$  hours provided only one failure occurs, and that at the end of the test.

For  $\gamma = .95$   $\chi^2_{.05,2} = 5.99$  &  $T \geq 3 M_T$

For  $\gamma = .99$   $\chi^2_{.01,2} = 9.21$  &  $T \geq 4.6 M_T$

NOTE: If the failure distribution is truly chance, as was assumed, then the  $2.3 M_T$  hours of test time may be accumulated on as many samples as desired (.1  $M_T$  hour on each of 23 samples, for example). However, in most test work this is not the case, and wearout failures do contribute to the failure rate. In complex devices, these wearout failures appear the same as chance failures. So if the above criteria are to be used, the number of test items must be limited so that each is tested long enough to allow the wearout of minor components to be a factor. A total test time on each sample at least equal to  $M_T$  is a minimum.

- The Two-Failure Case

$f = 2$ . Let  $\gamma = .90$ . Then  $\chi^2_{.10,4} = 7.78$

and  $T \geq M_T/2 (7.78) = 3.9 M_T$

NOTE: MTBF measured  $\geq 1.9 M_T$  and the test is assumed to have been terminated at the second failure. In example (1)  $M_M$  was  $2.3 M_T$ , so that it is seen that as  $f$  increases, the designer's margin of  $M_M$  over  $M_T$  may decrease. The total test time, of course, increases, but the test duration may be limited by using many samples.

For  $\gamma = .95$ ,  $\chi^2_{.05,4} = 9.49$

$T \geq 4.75 M_T$ ,  $M_M \geq 2.4 M_T$

For  $\gamma = .99$ ,  $\chi^2_{.01,4} = 13.28$

$T \geq 6.64 M_T$ ,  $M_M \geq 3.32 M_T$

- Test Design Example

Determine the test duration required to show, with 90% confidence, an MTBF of 1500 hours. The designer predicts a measured MTBF of at least 2300 hours for the test item.

From  $M_M \geq K M_T$ ,  $K \leq M_M/M_T = 2300/1500 = 1.53$

From Fig. 7 @  $\gamma = .90$ ,  $K = 1.53$

$f \geq 6$

The total test time will be about 13,800 hours. The test duration will be reduced if several samples are used (as many as 6).

**NOTE:** The test results may be checked as they become available, and if the MTBF requirement is met, the test may be terminated. If the test is not terminated at a failure,  $f$  must be increased by one. For example, if in the above test only three failures occur in 10,000 hours, the test can be stopped, since

from Fig. 7 @  $f = 4$ ,  $\gamma = .90$ ;  $K \geq 1.66$

i.e., with four failures, the MTBF margin factor,  $K$ , must be at least 1.66 to show within 90% confidence that  $M_A$  exceeds  $M_T$ . The actual  $K$  is calculated as follows:

$$M_M = 10000/4 = 2500, \text{ and}$$

$$\text{since } M_T = 1500, K = \frac{2500}{1500} = 1.66$$

The required  $K$  has been achieved and the test may be terminated.

#### 1.2.2.4 Test Acceleration Methods

##### A. Concept

The simplest method of test acceleration is to increase the speed or cycling rate of the test, provided detrimental temperature effects do not occur. In addition, the duration of a test program can often be significantly reduced by operating at higher than normal loads. Two conditions must be met if this technique is to be valid:

- The significant modes of failure are primarily load/cycle dependent, and not only time or cycle dependent.
- The slope of the load/cycles curve is known or can be estimated from previous experience.

The first condition is often not met, and in this case there are three points to consider:

- If the time-dependent effects are environmental, the accelerated rate of the environmental test methods can be considered to accelerate the time factor.
- If the time-dependent effects are not covered by environmental testing but are relatively minor in significance, the test can still be accelerated, but only by a factor of 1.5 or less.
- If the time-dependent effects are significant and not covered by environmental testing, the test should not be accelerated.

An example of an effect which is nearly independent of load is the wearout of a micro-switch, which is cycle dependent.

##### B. The Acceleration Exponent

The acceleration exponent is  $\delta$  in the following equation:

$$N = \left[ \frac{K}{L} \right]^\delta \quad \text{or} \quad L = \frac{K}{N^{1/\delta}} \quad (1)$$

where  $N$  is the number of cycles (or operating time in some cases) to failure at load  $L$ .  $K$  is a constant. This equation holds over at least a short range for most common materials and wearout phenomena. On log coordinates:

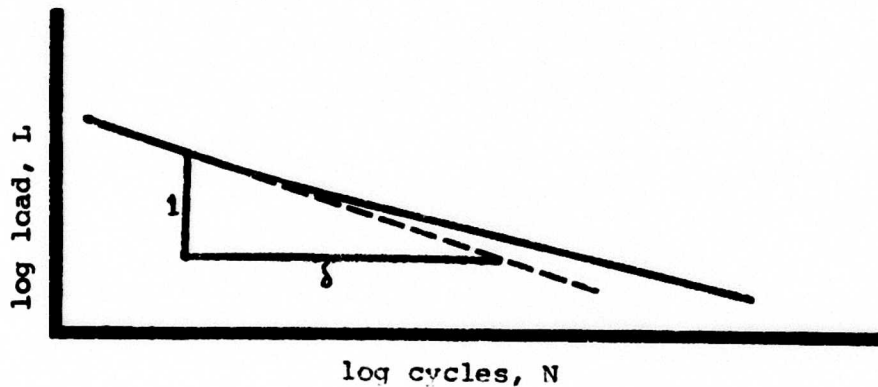


Figure 8. Illustration of Acceleration Exponent.

For structural fatigue, this is the familiar S-N curve available for all common materials. Since cargo handling devices are relatively low-cycle devices,  $\sigma$  is taken from the curve at 100,000 cycles or less. Since a number of factors affect the S-N curve shape depending on the specific application and since S-N data is not generally available for some of the non-metals which can be used in cargo handling systems, a comprehensive listing cannot be presented here. Two possible approaches exist:

- The contractor may determine the acceleration exponent based on small-specimen test data on the specific materials to be used, and design details of the test article.
- The following rule-of-thumb exponents may be used, which have been found to be adequate for most test programs:

Structural Fatigue	5.0
Gear Life	5.0
Bearing Life	3.3

It is recognized that the determination of a realistic acceleration exponent can be an extremely complex matter, especially if the test article is composed of many materials, of many sizes and shapes, and incorporates moving parts. It is conservative, however, to use the lowest exponent of all the component parts in the test article, since this yields the longest test. This does not mean that all components of the test article must run without failure or repair throughout the entire test -- only that any early failure must be evaluated in terms of its individual acceleration exponent. This is illustrated in the example at the end of this section.

### C. The Acceleration Factor

Once an acceleration exponent has been chosen, the acceleration factor, AF, can be determined. Equation 1 can be rewritten as

$$\frac{N_1}{N_2} = \left[ \frac{L_2}{L_1} \right]^\delta \quad (2)$$

where 1 and 2 are any two points on the "load vs cycle to failure" curve. The acceleration factor is the factor by which the equivalent aircraft time exceeds the actual test time due to the test's being run at a higher than normal load.

$$AF = \frac{N_A}{N_T} = \left[ \frac{L_T}{L_A} \right]^\delta \quad (3)$$

where subscript A refers to the aircraft condition and T refers to the test condition. An acceleration factor of 2, for example, can be produced, if the acceleration exponent is 3.3, with an increase in load of only 22%.

#### D. Load Prorating

Often the required life loading on a cargo handling device is expressed as a spectrum. When this is the case, the test can be accelerated by running at the high end of the spectrum for longer periods than the life spectrum specifies. In fact, a reasonable acceleration can often be achieved without exceeding the normal maximum load.

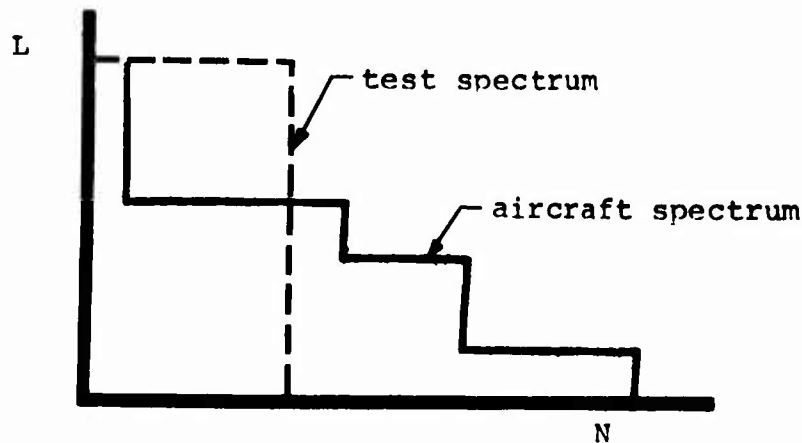


Figure 9. Example Loading Spectrums.

Each step in the aircraft spectrum can be described as  $N_i$  cycles at  $L_i$  load, where  $i$  varies from 1 to  $n$ , the number of steps. The number of cycles for an acceleration of the  $i$ th step at load  $L_T$  is

$$N = N_i \left[ \frac{L_i}{L_T} \right]^\delta$$

The total test duration is then

$$N_T = \sum_{i=1}^n N_i \left[ \frac{L_i}{L_T} \right]^\delta$$

The overall acceleration factor is defined as before:

$$AF = \frac{N_A}{N_T} \quad \text{where } N_A = \sum N_i$$

#### E. Example

A hoist test program is based on the 10,000-cycle life spectrum shown below:

<u>Load, Lb</u>	<u>Cycles</u>
20,000	1000
17,500	2000
15,000	4000
10,000	2000
5,000	1000

The hoist is constructed primarily of steel and is gear driven from a hydraulic motor. How many cycles at 20,000 lb are required to produce a conservative test?

Since bearings are involved, and have the lowest exponent, the 3.3 exponent determines the test length:

$$N_T = 1000 \left\{ 1 \left[ \frac{20000}{20000} \right]^{3.3} + 2 \left[ \frac{17.5}{20} \right]^{3.3} + 4 \left[ \frac{15}{20} \right]^{3.3} + 2 \left[ \frac{10}{20} \right]^{3.3} + 1 \left[ \frac{5}{20} \right]^{3.3} \right\}$$

$$= 3870 \text{ cycles at } 20,000 \text{ lb}$$

$$AF = \frac{10000}{3870} = 2.6$$

Since the gear and structural exponent is higher, these components will be subjected to a test of more than 10,000 equivalent cycles duration. The point at which the gears and structure meet the test requirement occurs at

$$N = \left\{ 1 + 2 \left[ \frac{17.5}{20} \right]^5 + 4 \left[ \frac{15}{20} \right]^5 + 2 \left[ \frac{10}{20} \right]^5 + 1 \left[ \frac{5}{20} \right]^5 \right\}$$

$$= 3030 \text{ cycles at } 20,000 \text{ lb}$$

In the example, only one test load was used and a fairly high acceleration factor results. With some components, particularly complex items such as hoists, this may be too severe due to distortion and abnormal wear patterns. Two recommendations are made for this case:

- Incorporate two or more steps in the test spectrum, allowing for normal equalization and "healing" of wear patterns. Randomize according to 3.1.2.2.B.
- Limit the acceleration factor to 2 or less.

## 2. COMPONENT TEST METHODS

### 2.1 INSTRUMENTS, CONTROLS, AND DISPLAYS

Components, instruments, controls, and displays for cargo handling systems do not differ in kind from those of other aircraft systems. It is only when these components are installed in a complete system that special requirements for cargo handling might be apparent. For this reason, existing specifications are considered adequate for testing at the component level. Testing as part of cargo handling systems is included in Section 3.

### 2.2 POWER SYSTEMS

As components or subsystems, power devices for cargo handling systems do not differ in kind from those of other aircraft systems. It is only when these components or subsystems are installed in a complete system that special requirements for cargo handling might be apparent. For this reason, existing specifications are considered adequate for testing at the component or subsystem level. Testing as part of a cargo handling system is included in Section 3.

### 2.3 HOISTS AND WINCHES

#### 2.3.1 Schedule of Tests

- A. Functional
- B. Strength
  - Limit Load Test
- C. Environmental
  - Vibration
  - Altitude
  - Fungus Resistance
  - Fluid Damage Resistance

### 2.3.2

#### Philosophy of Tests

The hoist/winch system tests of Section 3 will thoroughly test the winch or hoist as a component. Therefore, it is felt that a test article whose design employs present state-of-the-art concept applications need not be subjected to extensive component level testing. Exceptions shall be those tests where immediate operation of the test article is not essential and unique test environments and requirements can better be met with the component more accessible than when mounted in the environmental chamber, Figure 12, page 169 elevated in the facility illustrated in Figure 13, page 171. The vibration and altitude tests of Sections 1.1.2.1 and 1.1.2.4 respectively may be conducted on the test article of 3.1.2 in commercially available facilities specifically designed for the respective test. The fungus resistance test may be done on samples of non-metallic materials not already qualified.

New design concepts for major subsystems of the hoist or winch, such as transmissions, may be more rapidly wearout-tested on the component level, employing rapid cycling and/or accelerated loads, prior to or concurrent with the endurance test of 3.1 in order to minimize extended endurance testing. The same philosophy applies to fatigue testing on structural or any high-risk component.

Fluid damage resistance tests shall be conducted. Any deleterious effects revealed during component testing shall be included in the endurance test schedule and randomized with all other environmental parameters.

The limit load test shall be considered a demonstration of the design strength of the installed hoist or winch assembly and may be accomplished with the test article installed in a test fixture which will react loads applied through the cable under all conditions of cable angle and length, or drum wrap, required by the detail specification.

### 2.3.3 Methods and Procedure

At least one test article, as defined in Section 3.1.2, shall be subjected to all component-level tests of schedule 2.3.1, except fungus resistance as specified in Section 2.3.2, prior to the system endurance/environmental test of Section 3.1.

#### 2.3.3.1 Functional Test

The test article shall be demonstrated to be completely functional in accordance with Sections 3.1.3.1.1 and 3.1.3.1.2. All parameters shall be evaluated as specified and operational characteristics measured.

These measurements shall be recorded for control reference throughout all portions of the component and endurance test. All functions of the test article shall be demonstrated to perform within the established operating envelope of the detail specification. The functional test shall be conducted after each of the component tests as applicable.

#### 2.3.3.2 Limit Load Test

The test article shall be subjected to the limit load at all cable angles and lengths defined in the detail specification for 5 minutes at each condition. There shall be no permanent deformation as a result of any load application, unless so allowed by the detail specification.

#### 2.3.3.3 Environmental

##### A. Vibration

The test article shall be subjected to the vibration test schedule of Section 1.1.2.1.

##### B. Altitude

The test article shall be mounted in an altitude chamber and tested in accordance with Section 1.1.2.4.

C. Fluid Damage Resistance

The test article shall be tested in accordance with Section 1.1.2.5 for resistance to fluid damage. Any fluids found detrimental shall be included in the test schedule 3.1.1 of the system test for interaction evaluation.

D. Fungus Resistance

Samples of nonmetallic material shall be tested in accordance with Section 1.1.2.2. Consideration shall be given to interactions on materials exposed to commonly used fluids, such as hydraulic oil, and subsequent exposure to fungi in the test environment.

2.3.4 Accept/Reject Criteria

The test article shall perform within the detail specification requirements during the loaded and unloaded functional test. Any deviation shall be cause for rejection and determination of cause before proceeding with further testing. Any changes in design incorporated during component tests that might affect operational characteristics shall be cause for repeating the functional test prior to proceeding. No changes shall be incorporated in the remainder of the system exclusive of the test article between the first functional test of Section 3.1.3.1.1 and the pre-endurance functional test that might affect operating characteristics and test results.

Permanent deformation of any portion of the test article following application of limit load, except as pre-established in the detail specification, such as sacrificial liners, shall be considered cause for rejection.

Additional cause for rejection shall be degradation of materials during any tests, especially fungus and fluid damage resistance tests. Malfunctions, including seal leakage or deformation due to altitude or vibration tests, shall be further cause for rejection. Any allowable degradation shall be specified in the detail specification.

### 2.3.5

#### Description of Facilities

##### A. Functional

The functional test facilities shall consist of the system installation of Section 3.1.5 which provides for loaded and unloaded cycle operation. The hoist facility shall be functionally similar to Figure 13, page 171, while winches shall be tested in a facility similar to that shown in Figure 17, page 177.

##### B. Strength

The test article shall be mounted in its normal position attached at the design hard-points with fasteners of the proper size and strength. All support members, reaction arms, isolators, or other installation structural components shall be included. Provisions shall be incorporated in the mounting fixture to apply limit load to the test article through the cable at all conditions required by the detail specification. The fixture shall be capable of sustaining ultimate load without permanent deformation.

##### C. Environmental

- (1) Vibration tests shall be conducted in facilities with fixtures as defined in Section 1.1.2.1 and Method 514 of MIL-STD-810B. Vibration tables are available with the required control and measurement instrumentation.
- (2) Altitude test facilities are commercially available to apply the required altitude pressure and temperatures required by the detail specification in accordance with Section 1.1.2.4.
- (3) Fungus resistance should be conducted by a qualified laboratory or under controlled laboratory conditions which require a chamber capable of sustaining the conditions specified by Section 1.1.2.2.
- (4) Fluid damage resistance requires no special facility and requires only a device to apply the fluids specified in the detail specification in accordance with Section 1.1.2.5.

#### 2.3.6

#### Detail Specification Requirements

The detail specification for a hoist or winch shall define:

- A. Test article MTBF and wearout reliability requirements and confidence level on their verification.
- B. Design life, operational mission spectrum, and life spectrum.
- C. Normal operating cycle, operational parameters such as cable speed, response to input, overspeed protection, and limit switch tolerances.
- D. Rated load, limit load, cable load application angles, and allowable degradation.
- E. System components including operational and structural elements.
- F. Vibration test environment and duration.
- G. Altitude test environment and duration.
- H. Fluid damage resistance requirements.
- I. Statement of qualified material fungus resistance characteristics and additional fungus requirements not qualified, including interactions.
- J. Statement of established environmental resistance characteristics of materials used in component construction.

## 2.4 LOAD ISOLATORS

### 2.4.1 Schedule of Tests

#### Pre-Endurance Tests

- Functional Tests
- Proof Load
- Vibration
- Fungus Resistance
- Sunshine
- Altitude
- Fluid Damage Resistance
- Ice Accumulation
- Functional Tests

#### Endurance/Environmental Tests

- Endurance Cycling
- Sand and Dust
- Salt Spray
- Extreme Temperature
- Temperature Shock
- Humidity
- Rain

### 2.4.2 Philosophy of Tests

A load isolator is any device designed to provide spring and/or damping in a cargo handling system for the purpose of reducing adverse dynamic coupling between the load and the aircraft. This coupling is most visible in the phenomenon known as "vertical bounce," where a semiresonant condition exists at a frequency of rotor one per rev. The load isolator reduces the magnitude of the vibratory loads transmitted between the aircraft and the cargo handling system and, in addition, reduces the transient impulse when loads are lifted, braked, or released. The isolator can reduce "snapback" of the hook into the fuselage or rotor following a loaded release. Some form of load isolation has been found to be required on almost all helicopter cargo handling system installations.

Helicopter cargo handling system load isolators may take many forms. "Active" isolators are powered, that is, the displacement of the load is sensed, and a powered response takes place. Active isolators are used when the required spring/damper characteristics must remain constant over a wide range of loads and travels. "Passive" isolators are unpowered, but may use sophisticated means to achieve the required spring/damper characteristics. The simplest passive isolators are rubber "shock" mounts. A nonmetallic pendant may be designed to provide the required system isolation characteristics. A common application of a load isolator is a mounting that restricts the motion of a "swing"-mounted cargo hoist.

The recommended test program for load isolators is conducted in three phases: first, a comprehensive component-level test which uses analytically derived dynamic load and frequency inputs; second, when applicable, a system-level test where interface compatibility checks and transient, lifting cycle loadings are conducted; and finally, a flight test where system dynamic characteristics are checked for comparison to the test conditions used in the component-level and system-level tests. This three-phase program allows determination of load isolator reliability, compatibility, and performance, at the points in time where it is most efficient to do so.

This section covers the first phase of the program - the component-level tests. The basic reliability of the load isolator, when subjected to airframe vibratory inputs, is determined in this phase. The dynamic excitations used are those determined by analysis, since flight test results are usually unavailable at this point in the program. Often the prediction of the dynamic environment is changed during the program, due to system-level changes and analysis of flight test data. Even if this occurs, the component-level qualification is still valid, since the primary intent of this test is to verify the strength and life properties of the test article. This verification should not be affected by small changes in the input excitation.

At the system level, the test program will repeat some aspects of the component-level test, such as environmental exposure, but the excitation is different and therefore the effect of environments may be different. The excitation at the system level, when tested with a hoist, for example, is transient, that is, much lower frequency but higher amplitude than the airframe vibratory excitation.

At the flight test level, the actual operating characteristics and response of the entire system may be measured for comparison to predicted values. Since both the load isolator and the entire cargo handling system, including the isolator, have already met comprehensive strength and life test requirements, the flight test program does not need to dwell on the cargo handling system for an extended period of time.

It is recommended that all the tests listed in the Schedule of Tests be conducted, in the order indicated. It is recognized that all of the pre-endurance tests, except component functional tests, are also done at the system level and that it is not absolutely necessary to do them again at this level. It may be advantageous, however, to investigate the tolerance of the load isolator to these environments early in the program, avoiding design changes during system level testing. The criterion, then, for choosing the environments to be applied in pre-endurance testing is to apply those which may be an area of risk.

A similar situation exists in the endurance/environmental program except that the interaction with the type of excitation must be considered. The sand and dust test should never be deleted, but the others may be, after careful consideration.

The test facility for the load isolator component tests can be a conventional load or position feedback servo-controlled testing machine. The facility shall be capable of producing the required loading cycles and shall provide for the application of environments. The functional tests should include sweeps over the full range of frequencies and loads for which the isolator is designed. The endurance test length is determined by reliability requirements.

In the case where components serve a dual function, their load isolation characteristics can be periodically checked using these procedures and test facilities.

#### 2.4.3 Methods and Procedures

The following tests shall be conducted on each test article, if specified in the detail specification. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirement of the detail specification. The test is designed to be a "life" test, as defined in Section 1.2.2.3.

##### 2.4.3.1 Functional Tests

All functional features of the load isolator design shall be demonstrated according to the requirements of the detail specification. The functional test shall include measurement of the dynamic response characteristics of the load isolator. Input excitations shall be as determined by analysis and shall include frequency and amplitude sweeps over the full range of allowable excitations. The spring and damping rates of the load isolator shall remain within detail specification limits throughout the tests.

When the load isolator serves a dual function, such as lifting, positioning, or load measurement, these features shall also be fully tested to the limits of the detail specification.

##### 2.4.3.2 Proof Load Test

The load isolator shall be subjected to a static proof load equal to limit load for a period of 5 minutes. If the isolator can react load in more than one way - hydraulic lock and physical stops, for example - the proof load test shall be repeated for each condition.

#### 2.4.3.3 Pre-Endurance Tests

The remainder of the pre-endurance tests shall be conducted on each test article according to the applicable Sections of 1.1, Environmental Test Methods: 1.1.2.1 Vibration, 1.1.2.2 Fungus, 1.1.2.3 Sunshine, 1.1.2.4 Altitude, and 1.1.2.5 Fluid Damage Resistance. In addition, functional tests according to 2.4.3.1 shall be performed as required to monitor the effects of environments and at the conclusion of these tests.

Of these tests, sunshine, fungus, altitude, and fluid damage resistance may be deleted if the test article clearly will be unaffected by these environments, as stated in the detail specification. Sunshine and fungus testing may be performed on representative material samples of the test article, except for nonmetallic structural members, which are sunshine tested full size prior to endurance. In either case, if the test produces adverse results, the environment(s) shall be added to the endurance test.

#### 2.4.3.4 Endurance/Environmental Tests

Each test article shall be subjected to endurance cycling and each of the environmental tests listed under endurance tests in the Schedule of Tests, as specified in the detail specification.

The endurance cycle, the number of test articles, the duration of the test, and the test conditions shall be determined by the requirements of the detail specification and Section 1.2, Experimental Test Design. The environments shall be applied according to the applicable sections of 1.1, Environmental Test Methods: 1.1.2.7 Sand and Dust, 1.1.2.8 Salt Spray, 1.1.2.9 Extreme Temperature, 1.1.2.10 Temperature Shock, 1.1.2.11 Humidity, and 1.1.2.12 Rain. In addition, functional tests according to Section 2.4.3.1 shall be performed as required to monitor the effects of environment and at the conclusion of these tests.

The endurance test cycle shall be based on mission spectrum operation and shall include vibratory inputs as well as functional cycles. All environmental and endurance test conditions shall be randomized according to Section 1.2.2.2., Randomization. The endurance test may be accelerated in load using the procedures of Section 1.2.2.4, Test Acceleration Methods. Since the response of load isolators is generally frequency-sensitive, acceleration by increased frequency is recommended only when test article temperature is not greatly increased, and frequent functional tests are done.

The object of the endurance/environmental test program shall be to demonstrate the MTBF and wearout reliability requirement of the detail specification.

#### 2.4.4 Accept/Reject Criteria

As outlined in Section 1.2.2.3, Reliability Test Methods, there are two basic types of test failures to consider: wearout and "chance" failures. The wearout criterion is to be applied to nonrepairable major structural or primary wearout failures. The "chance" failure criterion is to be applied to the less important repairable failures usually considered in determining an MTBF for the load isolator design. Both requirements shall be a part of the detail specification, and the test program shall verify these requirements according to the provisions of Section 1.2.2.3, Reliability Test Methods.

Further causes for rejection are: damage or detrimental deformation in the proof load test, and failure to meet functional test requirements at any time during the test program.

#### 2.4.5 Description of Facilities

##### A. Pre-Endurance Test Facilities

Test chambers and facilities shall be used as required in the applicable parts of Section 1.1, Environmental Test Methods. Altitude, sunshine, and fungus test chambers are commercially available, as are vibration test tables of sufficient size to handle the test article.

## B. Endurance/Environmental Test Facility

The endurance environmental test facility shall be capable of providing the input loads, amplitudes, and frequencies required by the test program. The facility design should include provisions to apply proof load, although this can be performed on a separate test facility.

Provisions for the application of environment shall be made if required, according to the provisions of Section 1.1, Environmental Test Methods.

Test facility measurements shall include frequency, load, and displacement. These shall be recorded for analysis to determine spring rate, damping rate, and general frequency response.

### 2.4.6

#### Detail Specification Requirements

The detail specification for the load isolator shall include the following provisions:

- A. Definition of the isolator system and primary structural components.
- B. Definition of functional requirements and operational cycle.
- C. Specification of the design life, life spectrum, and mission spectrum.
- D. Specification of the system MTBF and wearout reliability requirements and confidence level on their verification.
- E. Specification of limit load, extreme cable angles, and any allowable proof load deformation.
- F. Specification of vibration test levels and test duration.
- G. Statement of known environmental resistance characteristics of materials used in the construction of the load isolator.
- H. Specification of fluid resistance requirements.

## 2.5 RIGGING POINTS

### 2.5.1 Schedule of Tests

- Proof Load
- Ultimate Load

### 2.5.2 Philosophy of Tests

Rigging points, or "hard points", are eaves, yokes, rings, or fittings permanently fixed to the aircraft, or cargo-carrying pod, for the purpose of securing a load. The rigging points may be designed to react lifting loads, to restrain a suspended load, to accept cargo tie-down straps, or to secure specific equipment such as pods, litters, or fuel cells.

The recommended test program consists of proof load and ultimate load tests. Due to the simplicity of rigging points, the low number of loading cycles, and the straightforward stress analysis involved, no dynamic or endurance test is required. The environmental tests can also be deleted, as long as the fittings are made from material whose properties are known to satisfy the environmental requirements of the detail specification.

Although rigging points are included here among components, the tests are conducted at a "system" level, that is, on the aircraft itself.

### 2.5.3 Methods and Procedures

Each rigging point on one test aircraft shall be subjected to these tests, except when there are several of identical design having identical backup structure. In this case, at least two of each design shall be subjected to the tests.

#### 2.5.3.1 Proof Load

Each test rigging point shall be subjected to a proof load test. The load shall be equal to limit load or two-thirds of the ultimate load requirement, whichever is larger. The load shall be applied for a period of 5 minutes at each extreme load-path angle, through the smallest standard shackle allowed for that rigging point capable of handling the proof load. Any evidence of slippage, rupture, or permanent deformation of the rigging point as a result of this test shall be cause for rejection.

#### 2.5.3.2 Ultimate Load Test

Each test rigging point shall be subjected to an ultimate load test. The load shall be equal to the ultimate load requirement of the detail specification. The angle of application of this load shall be the most critical allowable angle as determined by analysis. The duration of the application shall be one minute.

#### 2.5.4 Accept/Reject Criteria

In the proof load test, any evidence of slippage, rupture, or permanent deformation shall be cause for rejection. Additionally, any evidence of jamming, fouling, or other "functional" defects shall be cause for rejection.

In the ultimate load test, failure to react the test load for one minute shall be cause for rejection.

#### 2.5.5 Description of Facilities

Any means of applying the required loads through the required angles is acceptable.

#### 2.5.6 Detail Specification Requirements

The detail specification for the rigging point design shall include the following provisions:

- A. Definition of the rigging point design.
- B. Specification of limit load and the ultimate load requirement.
- C. Specification of extreme load angles.

## 2.6 EMERGENCY CARGO RELEASE SYSTEMS

### 2.6.1 Schedule of Tests

#### A. Functional Tests

#### B. Endurance/Environmental Tests

- Vibration
- Fungus Resistance
- Sunshine
- Altitude
- Fluid Damage Resistance
- Ice Accumulation
- Sand and Dust
- Salt Spray
- Extreme Temperature
- Temperature Shock
- Humidity
- Rain

### 2.6.2 Philosophy of Tests

The term emergency cargo release system is defined as the system used for the jettison of cargo when the primary release system is inoperable. There are many methods of emergency release, some of which are:

- explosive cable-cutting guillotines
- pyrotechnic circuits
- cable-operated devices
- hydraulic, electric, or pneumatic devices

Emergency release systems are the only part of an aircraft's cargo handling system considered to be safety-of-flight devices. As a result, these systems are usually redundant and incorporate self-test features which yield a high confidence in their performance. In spite of this, several occasions of inability to release a load in an emergency are known, and in other cases suspected, as a contributing cause in the loss of an aircraft. It is important, then, to improve the test procedures on these systems so that the intended system reliability is achieved through development.

The test program recommended here is on the "component" level, although a complete release system may be tested. It is on the component level that the basic reliability of the emergency release system is determined. The emergency release system is, of course, included in the "system" level test program and is subjected to all the environmental and induced stresses to which the system is exposed. Any failure of the emergency release system in the system-level tests is a matter for serious concern, since the test operating times are generally much less than the intended MTBF for the emergency release system. The cargo system test provides the best opportunity to evaluate the field maintenance and operational problems which sometimes lead to failure of the emergency release devices. In fact, it is human error which is the leading suspect in the failure of these devices to function when needed.

The reliability analysis of an emergency release system, which is beyond the scope of this report, is very important from a testing standpoint, since the very high system reliability requirements would yield an impractically long and costly test program. If analysis can show that parts of the total system may be tested to lower reliability requirements, a shorter test can result. When two systems are completely redundant, for example, the reliability of the two together is considerably higher than one alone, but the high reliability can be verified by tests on only one system.

The use of analysis can reduce testing costs in another way: the cost of testing a destructive device is much higher than that of testing a device which is unaffected by being tested. In the former case, the device cannot be retested, whether it operated as required or not; hence, many samples are required to obtain time-to-failure data. In the latter case, only a few samples are required. Now, if an emergency release system is composed of both destructive and nondestructive devices, separate test programs can be carried out at reduced cost, provided system analysis can establish valid reliability requirements for each component. An example of this would be an electrically fired cartridge guillotine. Many samples of the cartridge device are required, but only one or two of the electrical actuation systems need be tested.

The choice of test article(s), then, is based on a reliability analysis of the system. The test article could take on a very wide variety of forms -- anything from a simple toggle switch to a complete pyrotechnic release system.

The required reliability of each test article is verified using "chance failure" statistics as outlined in Section 1.2.2.3, Reliability Test Methods. The chance failure characteristic is considered to be the most common failure mode for emergency release systems, as opposed to "wearout" failures, since the effects of wear and degradation are generally carefully guarded against in the design of these systems. There may be some effects of wearout, however, and an analysis is presented in Methods and Procedures for determining if the observed test data follows the chance failure or the wearout characteristic.

The test program consists of a constant vibratory environment, the duration of which is the test time. In addition, environmental effects are simultaneously applied to the test article. Not all the environments listed in Schedule of Tests must be applied, since some devices may be inherently immune to some environments. Some devices, because of their placement within the aircraft, are not expected to encounter certain environmental extremes, negating the requirement for testing the device in that particular environment.

### 2.6.3 Test Methods

#### 2.6.3.1 Component Functional Tests

Because the components used in an emergency cargo release system may include a wide variety of devices, such as electrical switches and networks, hydraulic or pneumatic cylinders, cartridge-actuated devices, cable cutter assemblies, and mechanical cables and linkages, it is not possible to state here functional test requirements for all.

The requirements of the detail specification shall be met in all functional aspects of the system. This shall include at least two complete releases under load. The same test article may be used for all tests if the release is nondestructive. Dummy cables or fixtures may be used if the release action is destructive where a new test article is required for each test. In addition, two test articles shall be subjected to each of the following tests and shall properly function at the stabilized environmental condition produced in each case.

- altitude per Section 1.1.2.4
- fluid damage resistance per Section 1.1.2.5
- ice accumulation per Section 1.1.2.6
- extreme temperature per Section 1.1.2.9
- humidity per Section 1.1.2.11
- rain per Section 1.1.2.12

Cartridge-actuated devices shall be subjected to the test requirements of MIL-D-23615A, "Design and Evaluation of Cartridge Actuated Devices". When tests are defined both in MIL-D-23615A and in this report, the tests specified herein shall be performed.

#### 2.6.3.2 Endurance/Environmental Tests, Nondestructive Release Devices

Items whose functional ability may be demonstrated without their destruction and whose performance is not affected by repeated testing shall be tested in accordance with this section. This section is divided into three parts:

- A deals with the method of testing the component.
- B gives the data reduction method used based on the assumption that all failures are chance failures.
- C covers a method of checking the assumption made in part B.

- A. Each test item shall be subjected to a test which includes all the environments anticipated in flight, as specified by the detail specification. The environmental exposure shall be according to section 1.1, Environmental Test Methods. The duration of exposure to each environment shall be based on the detail specification, or in the absence of firm requirements, the standard environmental profile given at the end of the section. The test time shall be the vibration test time, which has an acceleration factor of unity.

The test shall be designed so that all components are tested for a period equal to their design life. Since, in general, the design life of a component is much longer than its required MTBF, a very few samples should be sufficient to demonstrate the required MTBF to the required confidence level, according to the requirements of Section 1.2.2.3, Reliability Test Methods.

Each test article shall be "interrogated" for proper functional operation at intervals equal to 1% of the design life or 10% of the target MTBF, whichever is smaller. Even smaller increments are desirable, if possible through continuous operation or by automated test methods. The time-to-failure of each test article shall be recorded. When the failure is "repairable", the repair may be made and the component returned to the test program.

- B. The observed MTBF is found simply by dividing the total number of failures into the total operating time of all the test articles in the test program. This quantity may be subjected to the acceptance methods of Section 1.2.2.3, Reliability Test Methods, both during and at the end of the test program. The test may be terminated when the MTBF requirement of the detail specification is verified, provided the chance failure assumption is verified using the procedures of the next paragraph.

- C. To demonstrate that the test results follow a constant failure rate characteristic, a Kolmogorov-Smirnov test is used (References 4 and 5), as outlined below and illustrated in Figure 10, page 76.
- (1) Plot normalized cumulative failure,  $C$ , against test time. Normalized cumulative failures are defined as the total number of failures which occurred up to time  $t$  divided by the total number of failures observed in the complete test program.
  - (2) Plot a straight line from the origin to the end of the actual failure line. The straight line is the line which the test data will follow if the phenomenon under test is chance failure.
  - (3) From Figure 11, page 77, find  $E$ , the width of the band which will encompass the data if it is a chance failure phenomenon. The level of confidence for the choice of  $E$  should be specified in the detail specification.
  - (4) If the failure line exceeds the low limit line, the phenomenon contains enough of a wearout characteristic to reject the chance failure hypothesis. This case is discussed further in Section 2.6.3.4, Wearout Failure Analysis. If the failure line exceeds the high limit line at any point, the phenomenon contains enough of a "constant" failure characteristic to reject the chance failure hypothesis. This may or may not be acceptable, depending on whether the MTBF requirement is met for low operating times.

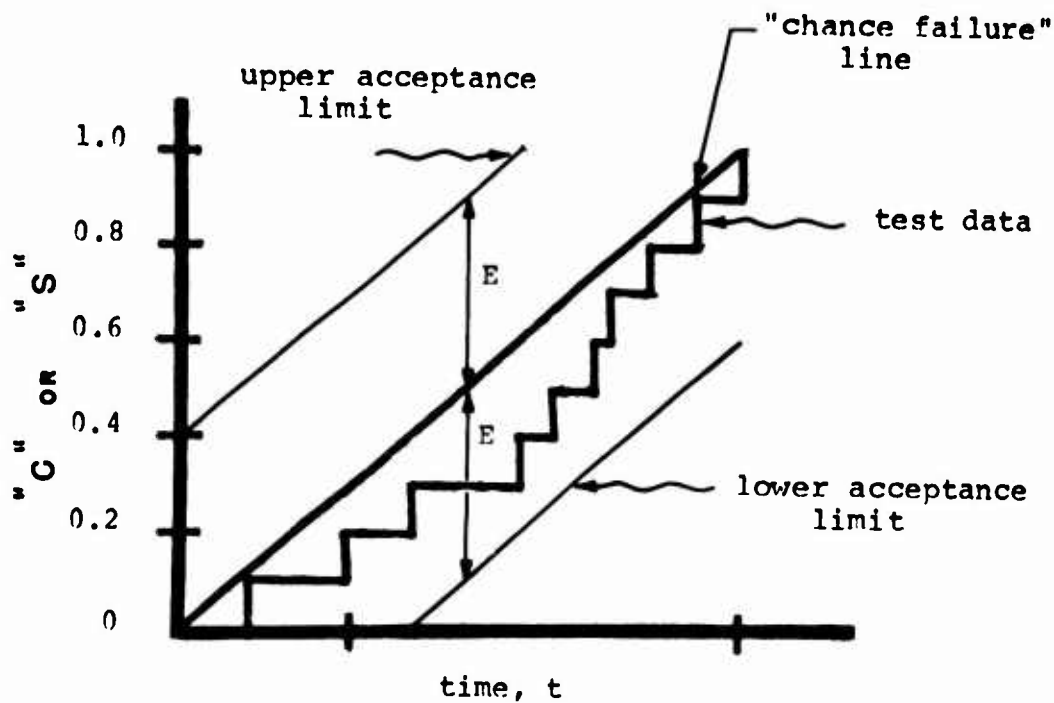


Figure 10. Kolmogorov-Smirnov Method.

In the above figure:

C = normalized cumulative failures, used for nondestructive testing

$$C = \frac{\text{total failures up to time } t}{\text{total failures in the test program}}$$

S = normalized segment failures, used for destructive, segment testing

$$S = \frac{\text{total failures in a segment}}{\text{total failures in the final segment}}$$

E = width of acceptance band using Kolmogorov-Smirnov statistics, Figure 11.

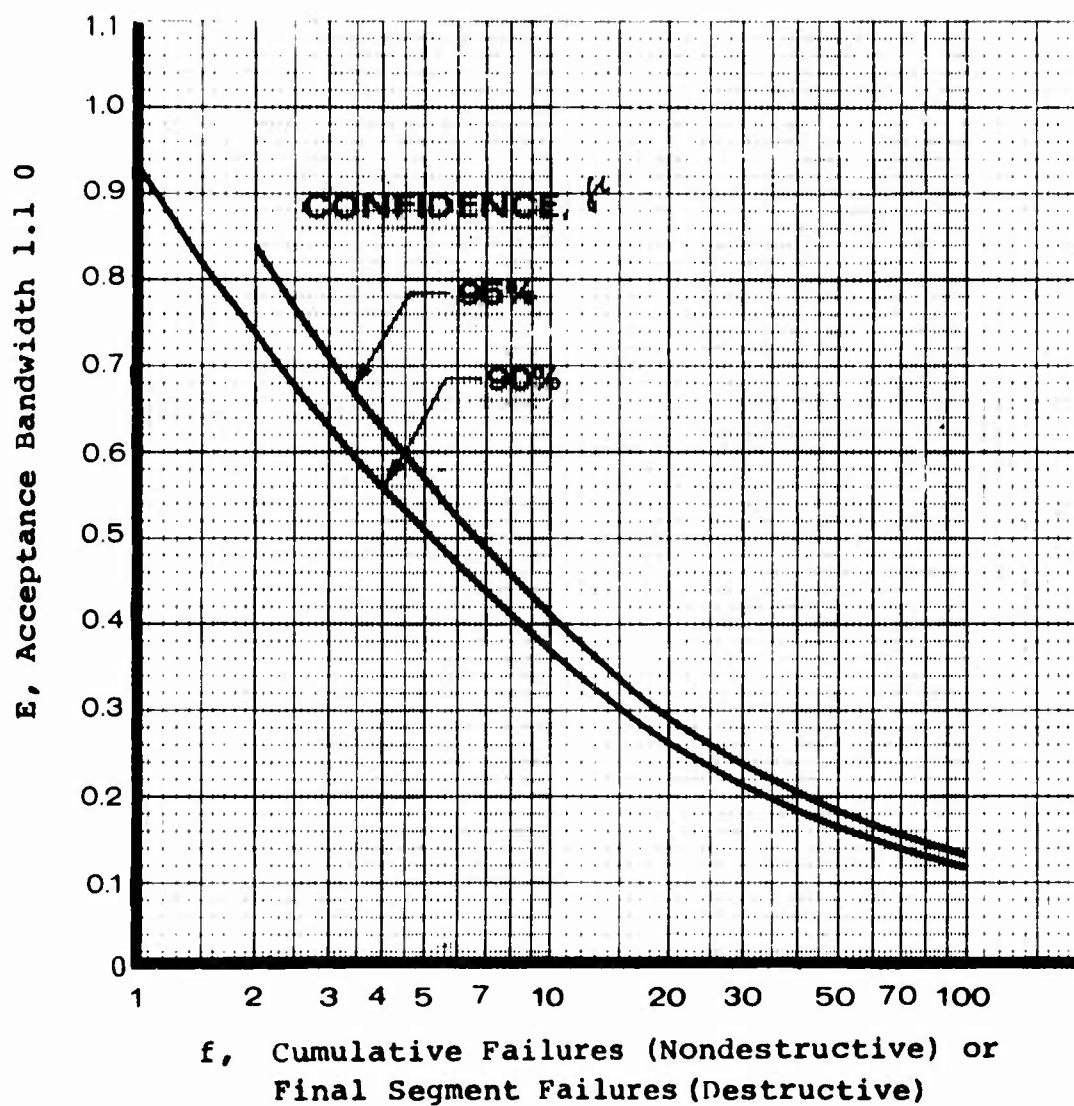


Figure 11. Kolmogorov-Smirnov Acceptance Limits.

#### 2.6.3.3 Endurance/Environmental Tests, Destructive Release Devices

Items whose functional ability cannot be demonstrated without their destruction shall be tested in accordance with this section, which is divided into three parts:

- A deals with the method of testing the component.
  - B gives the data reduction method to be used, based on the assumption that all failures are constant-rate chance failures.
  - C covers a method of testing the assumption made in part B.
- A. The number of test articles shall be determined using the procedure of Section 1.2.2.3, Reliability Test Methods, the provisions of the detail specification, and the following discussion. Since each test article is destroyed whether it fails to operate or not, a segmented test plan of a duration equal to the design life is required. At the end of each segment of the test, a fraction of the test articles are subjected to test. If there were 100 segments, 1% of the total lot of test articles would be tested at the end of each segment. The segments shall be equal to 5% of the design life, or 20% of the target MTBF, whichever is smaller. Even smaller increments may be used.

This test method provides a "cumulative failure" result at each segment. For example, if a cartridge fails to fire after 300 hours of testing, there is no way of knowing the time at which the cartridge became inoperative; conversely, there is no way of knowing how long beyond 300 hours the cartridges which did fire would remain operative. Each segment, however, must be considered to be a representative sample of the population of test articles, and if the entire population were "interrogated" at that time, the same fraction would fail. The inevitable inaccuracies in this extrapolation are compensated for in the number of segments tested and the subsequent "fairing" of the failure curve.

Each test item shall be subjected to a test which includes all the environments anticipated in flight, as specified in the detail specification. The environmental exposure shall be according to Section 1.1, Environmental Test Methods. The duration of exposure to each environment shall be based on the detail specification or, in the absence of firm requirements, the standard environmental profile given at the end of this section.

- B. Same as part 2.6.3.2.B.
- C. Same as part 2.6.3.2.C except that the vertical axis in Figure 10 is S, normalized segment failures. Normalized segment failures are defined as the number of failures in any segment divided by the number of failures in the final segment. This may be recognized as basically the same variable as normalized cumulative failures but modified to use the "cumulative" nature of segment testing.

#### 2.6.3.4 Wearout Failure Analysis

- A. It is recognized that the testing required to demonstrate satisfactory safety-of-flight reliability for components exhibiting wearout failure is, in general, prohibitive. However, since certain special cases may present themselves where it is necessary to demonstrate test article longevity, the following are the recommended procedures:
  - 1. For a test article whose functional ability may be determined without damage to the test article, an endurance test similar to that described in Section 2.6.3.2 may be used. The test shall consist of applying, in a randomized test plan, the environments which the test item is anticipated to encounter. The observed life and subsequent statistical inferences about the test article's true mean life are as covered in Section 1.2.2.3, Reliability Test Methods.

2. Test articles whose functional ability may not be demonstrated without destruction or interaction are tested according to this section. The environmental test procedure shall be similar to that described in Section 2.6.3.3A, the difference being that the test duration shall be extended past the required design life of the test article.

Based on the data obtained from the above experiment, an estimation may be made of the mean life and standard deviation by either the Karber Method or Probit Method of analysis as described in Chapter 10 of Reference 6. Using Hald's equation, as described in Section 1.2.2.3, and standard probability tables, an estimate may be made, with a given confidence level, as to the reliability of the test article at the design life.

#### 2.6.3.5 Standard Environmental Profile

The following is the environmental test time profile that shall be applied to emergency cargo release systems and their components in the absence of a profile specified in the detail specification. The conditions shall be randomized according to Section 1.2.2.2, Randomization:

<u>Condition</u>	<u>% of Test Time Applied</u>
-65°F	5
-25°F	15
130°F	5
160°F	5
Sand & Dust per Section 1.1.2.7	5
Salt Spray per Section 1.1.2.8	10
Humidity per Section 1.1.2.11	20

The amount of test time allotted to these specific tests is 65% of the total test time. The remaining 35% of the test time shall be allotted to other environmental tests to be performed, as applicable, and testing at ambient conditions.

#### 2.6.4 Accept/Reject Criteria

Design rejection criteria shall include the following:

- A. Failure to meet functional requirements.
- B. Failure to establish target MTBF to required confidence level.
- C. Deviation outside acceptable limits from constant-failure-rate model.

Criteria B and C may be superseded by specific requirements in the detail specification.

#### 2.6.5 Facilities Requirements

The endurance/environmental test chamber required is similar to that shown in Figure 16, page 175. The chamber shall be equipped to provide vibration excitation at the frequencies and amplitudes required. The vibration source must be able to operate while environments are being applied.

#### 2.6.6 Detail Specification Requirements

The detail specification for the emergency release system shall include the following provisions:

- A. Complete functional requirements.
- B. Target MTBF and required confidence level on its substantiation, if the constant-failure-rate reliability model is used. The required reliability of the system and a reliability analysis of the system shall determine the reliability requirement for each component.
- C. If other than the constant-failure-rate reliability model is used, the following shall be specified:
  - (1) The component reliability model and the required level of confidence to be used to verify that the model is correct.
  - (2) The required reliability and confidence level of its substantiation.
- D. Specification of the expected environmental profile.

## 2.7 HOISTING AND WINCHING CABLES

### 2.7.1 Schedule of Tests

- (1) Proof Load
- (2) Rough Handling
- (3) Fungus
- (4) Fluid Damage Resistance
- (5) Sunshine
- (6) Endurance-Environmental - to include:  
Extreme Temperature, Rain, Humidity, Salt  
Spray, and Sand and Dust
- (7) Residual Breaking Strength

### 2.7.2 Philosophy of Tests

This section deals with that component of the cargo handling system which is the flexible tension member connecting the system's hoist or winch with the cargo hook assembly. This component will be referred to as a cable. The cable differs from other cargo handling system flexible tension members in that it is stored on a drum and is flexible while coiling or uncoiling during operation. The cable can be manufactured of various materials, both metallic and textile. It can also have different cross sections, such as circular or flat ribboned. In addition, cables may contain conductors for the purpose of signal transfer between the cargo hook and the system control point.

Cargo handling system cables must operate in very hostile environments. They have been known to be dragged along paved and dirt runways, lowered into sand, seawater, mud, and wet concrete, run over by passing vehicles, snagged in trees, and doused with aviation fuel during a spill. Normal usage often includes wrapping under full load, instant load release, spinning under load, and exposure to all weather elements.

The design of the test program for a specific cable should include a review of all the tests listed in 2.7.1. The construction of a specific design may negate the requirement for some testing; for example, a cable made from a flat stainless-steel ribbon might be exempt from fungus, sunshine, humidity, and rain tests.

It is intended that all scheduled tests be performed in the order stated on all test articles. Fungus tests can be performed on a material sample, and must be performed prior to endurance testing. Should fungus test results indicate that the material samples have been adversely affected, then the fungus environment must be included on the endurance-environmental test specimens prior to the start of endurance testing or the cable material selection must be reviewed. Sunshine and fluid damage resistance tests shall be performed on the endurance test articles prior to the start of endurance testing.

Thus, the order of testing will expose the endurance test articles to rough handling, fluid damage resistance, and sunshine prior to endurance. The results of these tests might not appear to be significant by themselves but may interact later with the endurance-environmental test to reveal a deficiency.

The number of test articles is determined by the specified reliability requirements according to Section 1.2.2. Since cable assemblies may be of considerable length, practicality may indicate test articles of shorter length. If this is required, the minimum specimen length shall be sized to maintain at least 50 diameters of cable, exclusive of end connections or splices, within the environment of the endurance test apparatus at all times during operation. The test articles must duplicate the full-scale cable assemblies in every aspect except length. This shall include the cable's production end fittings.

### 2.7.3

#### Methods and Procedures

The following tests shall be conducted on the test articles. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. The test program is designed to be a "strength" test, with "residual breaking strength" as the primary statistical parameter as defined in Section 1.2.2.3.

#### **2.7.3.1      Proof Load Test**

All cable test specimens shall be subjected to a proof load test. The proof load shall be specified by the detail specification or, in the absence of a specified proof load, shall be 40 percent of the ultimate load requirement. Load shall be applied through the cable's production end-fitting configuration and shall be applied gradually. Proof load shall be maintained for a minimum of five minutes. At the conclusion of the proof test, the cable shall be examined for evidence of slippage, rupture, broken sewing thread, or frayed webbing. For many cable constructions, some permanent deformation is normal and should be anticipated. Permanent deformation shall not exceed that allowed by the detail specification.

#### **2.7.3.2      Rough Handling Test**

All cable test specimens shall be tested in the test box shown in Figure 14, page 172, and described in Section 2.7.5. The cable shall be inserted in the box with a cargo hook installed on one end or a mass of similar geometric shape and weight. The box shall contain a dry aggregate of approximately 4 cubic feet of 2- to 3-inch sharp-edged traprock (approximately 1 foot depth in a corner) and 1 cubic foot of masonry type sand. The test specimen and the aggregate shall be tumbled by rotating the box at 15 rpm for 1 hour. Upon removal of the cable, it shall be inspected for detrimental physical damage. The integrity of operation of any signal transmission conductors shall be verified.

#### **2.7.3.3      Fungus Test**

At least one cable test specimen or samples of all nonmetallic materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

#### **2.7.3.4      Fluid Damage Resistance Test**

All cable test specimens shall be subjected to a fluid damage resistance test in accordance with Section 1.1.2.5.

#### 2.7.3.5 Sunshine Test

All cable test specimens shall be subjected to a sunshine test in accordance with Section 1.1.2.3.

#### 2.7.3.6 Endurance-Environmental Test

(1) The combined endurance-environmental test shall be performed in the test apparatus shown in Figure 15, page 173, and described in Section 2.7.5. The test loading and environmental programs shall be constructed in accordance with the detail specification for the cable and the guidelines of Section 1.2, Experimental Test Design. Due consideration must be given to all of the operating parameters. These shall include:

- load
- load application rate
- loading duration
- time unloaded
- number of cycles at each load
- environmental conditions
- linear cable speed
- working bend radius

(2) The following environmental tests shall be combined with the endurance test loading program:

- Extreme temperature test in accordance with Section 1.1.2.9.
- Rain test in accordance with Section 1.1.2.12.
- Humidity test in accordance with Section 1.1.2.11.
- Salt spray test in accordance with Section 1.1.2.8.
- Sand and dust test in accordance with Section 1.1.2.7.

(3) Periodic functional tests shall be scheduled in phase with the endurance test blocks to verify any operational requirements of the cable design. An example would be a check on the continuity of conductors within a cable.

#### 2.7.3.7 Residual Breaking Strength Test

Tests shall be performed to determine the residual breaking strength of all test specimens. Load shall be applied through the cable's production end-fitting configuration at the maximum estimated design load application rate. Load shall be increased until the cable parts. The data shall be analyzed statistically to demonstrate that the residual breaking strength meets the reliability requirements at design limit load as shown in Section 1.2.2.3, Reliability Test Methods.

#### 2.7.4 Accept/Reject Criteria

##### (1) Structural

The basic goal of the test program is to demonstrate the reliability requirement in the data obtained from the residual breaking strength data at the end of the test program. Any structural test result which will impair this goal earlier in the test program shall be reason for rejection of the cable design. These may appear at any point during the test program should the test cables fail to react applied load or show evidence of detrimental deformation. It should be noted that cables, especially nonmetallic assemblies, may exhibit some permanent deformation as a result of high-load application. This shall be acceptable, providing that the deformation does not impair its ability to perform its operational requirements and does not exceed the limits allowed by the detail specification.

##### (2) Operational

A cable design shall be considered to be rejected if, as a result of any test, it fails to perform its operational requirements. An example of this would be deformation to the point that the cable would slip in nonadjustable wrap tensioning rollers in its intended winch application. Also, a cable containing signal conductors shall be considered to have failed should these conductors fail to transmit required intelligence at any phase of testing.

## 2.7.5

### Description of Facilities

#### (1) Proof Load and Residual Breaking Strength Facility

This facility must be capable of applying the required tensile loads at controllable rates. It is suggested that load be applied to the hook or free end of the cable through a swivel by adaptation to the production end fitting. Normally the winch or hoist end will require a specified number of wraps on a simulated winch or hoist drum in order to secure that end.

#### (2) Rough Handling Facility

The rough handling facility utilizes the tumbling box illustrated in Figure 14, page 172. This provides random simulation of being dropped, dragged, or swung into hard objects. Additionally, abrasive and cutting actions resulting from being dragged are introduced with the sharp abrasive aggregate of traprock and masonry sand.

#### (3) Endurance-Environmental Facility

The endurance test apparatus is pictured in Figure 15, page 173. The suggested apparatus has the capability of testing two cable specimens at one time. Test environments shall be applied to that portion of the cable being flexed over the minimum design bend radius pulleys within the test chamber. The apparatus shall be sized to allow a minimum of 50 diameters of the cable to remain within the chamber during all extremes of motion. The test chamber shall provide the required test environments in a manner similar to the chambers shown in Figures 12, page 169, and 16, page 175, for cargo hoist and hook tests. The cable tensile loading system shall provide the capability of programming the test loads required by the randomized endurance load blocks. This will include load, load rate, and load duration as they relate to cable motion. This could be as simple as a hand pump and hydraulic cylinder for simple test programs or as complex as a tape programmed electro-hydraulic servo system for more complicated

loading requirements. Cable motion, amplitude, and speed shall be provided by driving the apparatus with an oscillating motion through appropriate arcs. Twisting motions of the test cable and the loading elements shall be isolated from each other by the use of swivel connections at each end of the cables.

#### 2.7.6 Detail Specification Requirements

The detail specification for hoisting and winching cables shall include the following provisions:

- (1) Definition of the design life, life spectrum loading, and mission spectrum requirements.
- (2) Specification of the wearout reliability requirement and confidence level on its verification.
- (3) Specification of limit load, proof load, and respective loading rates.
- (4) Specification of fluid resistance requirements.
- (5) Statement of established environmental resistance characteristics of materials used in cable construction.
- (6) Performance requirements for any features such as signal conductors.
- (7) Specification of minimum working bend radius.

### 2.8 PENDANTS

#### 2.8.1 Schedule of Tests

- (1) Proof Load
- (2) Rough Handling
- (3) Fungus
- (4) Fluid Damage Resistance
- (5) Sunshine
- (6) Operational Tests

(7) Endurance-Environmental, to include:  
Extreme Temperature, Rain, Humidity, Salt  
Spray, and Sand and Dust

(8) Operational Tests

(9) Residual Breaking Strength

## 2.8.2

### Philosophy of Tests

A pendant is the tension member, usually flexible and not adjustable in length, interconnecting an aircraft attachment point and a load attachment point such as the apex of a sling or cargo net. Pendants provide clearance between the aircraft and the materiel to be carried to simplify load hookup and to keep the materiel from striking the aircraft during flight maneuvers or load oscillations. Some pendants provide dynamic response characteristics required to avoid objectionable vertical bounce characteristics. Pendants can be made from varied metallic and non-metallic materials. They may have numerous different cross-sectional shapes. A pendant design could include conductors for the purpose of signal transfer between the aircraft and a cargo hook used at the lower end of the pendant. Pendants, being used external to the aircraft, are exposed to all of the environments that the aircraft can operate in. Their length is such that they can be dragged and abused during takeoff, landing, or taxiing. Handling by ground personnel can introduce additional abuses.

Testing of pendants shall include consideration of all of the scheduled tests of Section 2.8.1 in the specified sequence. The schedule is designed to provide conservative assurance that the pendant will perform its mission life even though it has encountered rough handling and environmental hazards along the way. This is the way service components are used. The schedule does not account for the material or complexity of a pendant design, and it may be that a simple design, using material of well-known properties, may not require every test specified.

All tests except fungus tests shall be performed on full-scale test specimens, and the same test item shall be used throughout the program. Fungus tests can be performed on material samples, but they must be performed prior to endurance testing. Should fungus test results indicate that the material samples have been adversely affected, then the fungus environment must be included on the endurance-environmental test specimens prior to the start of endurance.

Should the design of the pendant include dynamic response characteristics to meet load isolation requirements, then the schedule must include tests to demonstrate these characteristics. These tests are considered operational tests. As shown in the schedule, these tests shall be performed prior to and following the endurance tests, since it is not known if the rigors of endurance will change these characteristics. When a long endurance program is required, it is recommended that some spot checks also be made throughout the endurance test to monitor for any change. Other checks which might be considered operational tests, such as conductor integrity, shall be considered a part of these operational tests.

### 2.8.3

#### Methods and Procedures

The following tests shall be conducted on the test articles. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. The test program is designed to be a "strength" test, with "residual breaking strength" as the primary statistical parameter as defined in Section 1.2.2.3.

#### 2.8.3.1 Proof Load Tests

All pendant test specimens shall be subjected to a proof load test. The proof load shall be specified by the detail specification or, in the absence of a specified proof load, shall be 40 percent of the ultimate load requirement. Load shall be applied through the pendant's production end fittings and shall be applied gradually. Proof load shall be maintained for a minimum of five minutes. At the conclusion of the proof test, the pendant shall be examined for evidence of slippage, rupture, broken sewing thread, or frayed webbing. For many pendant constructions, some permanent deformation is normal and should be anticipated. Permanent deformation shall not exceed that allowed by the detail specification.

#### 2.8.3.2 Rough Handling Test

All pendant test specimens shall be tested in the test box shown in Figure 14, page 172, and Section 2.8.5. The pendant shall be inserted in the box with its production end fittings. If a cargo hook is a part of the production configuration, the hook or a mass of similar geometric shape and weight shall be attached. The box shall contain a dry aggregate of approximately 4 cubic feet of 2- to 3-inch sharp-edged traprock (approximately 1 foot depth in a corner) and 1 cubic foot of masonry type sand. The test specimen and the aggregate shall be tumbled by rotating the box at 15 rpm for 1 hour. Upon removal of the pendant, it shall be inspected for detrimental physical damage. The integrity or operation of any signal transmission conductors shall be verified.

#### 2.8.3.3 Fungus Test

At least one pendant test specimen or samples of all nonmetallic materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

#### 2.8.3.4 Fluid Damage Resistance Test

All pendant test specimens shall be subjected to a fluid damage resistance test in accordance with Section 1.1.2.5.

#### 2.8.3.5 Sunshine Test

All pendant test specimens shall be subjected to a sunshine test in accordance with Section 1.1.2.3.

#### 2.8.3.6 Operational Tests

Operational tests shall be performed on all pendant test specimens. These tests shall be designed to demonstrate any pendant operational requirements which are secondary to the primary load-carrying function. For example, one such requirement might be dynamic response characteristics to meet load isolation requirements. In this case, the pendants would be subjected to functional tests similar to those performed on any load isolator as described in Section 2.4. A requirement to transmit signals to a cargo hook would be a second example. A test of the functioning of the signal conductor would be required.

#### 2.8.3.7 Endurance-Environmental Test

(1) The combined endurance-environmental test shall be performed in the test apparatus shown in Figure 16, page 175, and described in section 2.8.5. The test loading and environment programs shall be constructed in accordance with the detail specification for the pendant and the methods of Section 1.2, Experimental Test Design. The test program shall consider all of the operating parameters. These shall include:

- load
- load application rate
- load duration
- time unloaded
- number of cycles of each load
- environmental conditions

(2) The following environmental tests shall be combined with the endurance test loading program:

- Extreme temperature test in accordance with Section 1.2.1.9.
- Rain test in accordance with Section 1.2.1.12.
- Humidity test in accordance with Section 1.2.1.11.
- Salt spray test in accordance with Section 1.2.1.8.
- Sand and dust test in accordance with Section 1.2.1.7.

(3) Periodic functional tests shall be scheduled in phase with the endurance test blocks to verify any operational requirements of the pendant design. Example would be a check on the continuity of conductors within a pendant, or a check of load isolation characteristics.

#### 2.8.3.8 Residual Breaking Strength Test

Tests shall be performed to determine the residual breaking strength of all test specimens. Load shall be applied through the pendant's production end fittings at the maximum estimated design load application rate. Load shall be increased until the pendant parts. The data shall be analyzed statistically to demonstrate that the residual breaking strength meets the reliability requirements at design limit load as shown in Section 1.2.2.3, Reliability Test Methods.

Accept/Reject Criteria(1) Structural

The basic goal of the test program is to demonstrate the reliability requirement in the data obtained from the residual breaking strength data at the end of the test program. Any structural test result which will impair this goal earlier in the test program shall be reason for rejection of the pendant design. These may appear at any point during the test program should the test pendants fail to react applied loads or show evidence of detrimental deformation. It should be noted that pendants, especially nonmetallic assemblies, may exhibit some permanent deformation as a result of high-load application. This shall be acceptable, providing that the deformation does not impair its ability to perform its operational requirements and does not exceed the limits allowed by the detail specification.

(2) Operational

A pendant design shall be considered rejected if the results of any test would make it fail to meet its operational requirements. An example of this would be a change in dynamic response characteristics sufficient to make the pendant fail its load isolation requirements. Also, a pendant containing signal conductors shall be considered rejectable should these conductors fail to transmit required intelligence at any point in the test program.

## 2.8.5

### Description of Facilities

#### (1) Proof Load and Residual Breaking Strength Facility

This facility must be capable of applying the required tensile loads at controllable rates. It is suggested that load be applied to the hook or free end of the pendant by adaptation to the production end fitting.

#### (2) Rough Handling Facility

The rough handling facility utilizes the tumbling box illustrated in Figure 14, page 172. This provides random simulation of being dropped, dragged, or swung into hard objects. Additionally, abrasive and cutting actions resulting from being dragged are introduced with the sharp abrasive aggregate of trap-rock and masonry sand.

#### (3) Endurance-Environmental Facility

The endurance-environmental apparatus is pictured in Figure 16, page 175. Test environments shall be applied by the test chamber illustrated. The pendant shall be installed in a manner similar to the sling leg shown in the inset to the figure. If the pendant is long and upper and lower end fitting configurations are similar, only one end fitting and approximately 25 percent, or a minimum of 4 feet, need be exposed to the full environmental atmosphere. The pendant tensile loading system shall provide the capability of programming the test loads required by the randomized load blocks. This will include load, load rate, and load duration. This can be as simple as a manually controlled hydraulic system for simple programs, or as complex as a completely automated cycling and loading system for major programs.

#### 2.8.6 Detail Specification Requirements

The detail specification for pendants shall include the following provisions:

- (1) Definition of the design life, life spectrum loading, and mission spectrum requirements.
- (2) Specification of the wearout reliability requirement and confidence level on its verification.
- (3) Specification of limit load, proof load, and respective loading rates.
- (4) Specification of fluid resistance requirements.
- (5) Statement of established environmental resistance characteristics of materials used in pendant construction.
- (6) Performance requirements for any features such as dynamic response characteristic for load isolation.
- (7) Performance requirements for any features such as signal conductors.

#### 2.9 CARGO HOOK ASSEMBLIES

##### 2.9.1 Schedule of Tests

- (1) Functional Tests
- (2) Emergency Release System
- (3) Proof Load
- (4) Pre-Endurance Test Program consisting of:
  - Rough Handling
  - Vibration
  - Altitude
  - Fungus Resistance
  - Ice Accumulation
  - Sunshine
  - Fluid Damage Resistance

(5) Combined endurance/environmental survivability test consisting of functional test cycles and the following:

- Extreme Temperature
- Fluid Damage Resistance
- Ice Accumulation
- Sand and Dust
- Salt Fog
- Temperature Shock
- Humidity
- Immersion

(6) Emergency Release System

## 2.9.2

### Philosophy of Tests

The term "cargo hook assemblies" includes those hooks, along with any attendant swivels, keepers, normal and emergency release mechanisms, and other devices, which are used for directly lifting, supporting, positioning, and/or restraining materiel. Cargo hook assemblies are used externally and internally, with hoist systems, with winch systems, on tie-downs and other cargo restraining devices, and in a variety of other cargo handling applications.

The cargo hook is the "working" end of a cargo handling system and is often subjected to considerably more abuse than the rest of the system. The cargo hook can usually be separated by a considerable distance from the aircraft environment and subsequently is treated with much less respect, often by people who know or care little about the sometimes fragile nature of aircraft components. External cargo hooks see the worst of all the abusive environments - sand and dust, salt, mud, ice, extreme temperatures, and immersion; in addition, they are abusively handled - dropped on runways, swing into vehicles, dragged on the ground and through trees; then, they are not properly maintained.

Previous test programs have not provided coverage for extremely rough handling and the interaction between operation and environments, which are responsible for the majority of cargo hook assembly failures in recent experience. The test program recommended here incorporates a "tumble-box" rough handling test on all test specimens, the effects of which, if not immediately apparent,

are felt throughout the remainder of the environmental/endurance test program. Similarly, vibration, altitude, fungus resistance, and sunshine tests are not thought to interact directly with the simultaneous operation of the hook assembly and so are applied prior to endurance testing, where their damage, if any, is exaggerated. Of course, for simple hooks, not all of the tests are applicable, and these may be deleted if justification is provided in the detail specification.

Emergency release system tests are scheduled at the beginning and at the end of the test program. If this system is nondestructive, it is, in addition, included in the periodic functional tests of the hook assembly. If the system is destructive, as with explosive bolts, a dummy test setup may be used; that is, the destructive devices may be removed, after exposure to all test conditions, from the cargo hook assembly and reinstalled for test in a test fixture duplicating the cargo hook with regard to emergency release characteristics.

Two tests - ice accumulation and fluid damage resistance - may or may not have an interaction with operation and wear. For this reason, it is recommended that they be performed both prior to endurance - to obtain "baseline" effects - and during endurance - to obtain interactions. The fluid damage resistance test prior to endurance exposes the hook for 3 hours to all the fluids it could see in service. The fluid damage resistance test during endurance only uses those fluids which commonly wet the hook during service, or those which were observed to have a harmful effect during pre-endurance tests.

The endurance/environmental program, in addition to endurance test cycling based on the operational cycle and functional requirements, simultaneously applies environments in a randomized block test design. Unless specifically authorized and justified in the detail specification, all the environments listed in Schedule of Tests shall be applied. The number of test samples and the duration of the tests are dependent on the reliability requirements for wearout and mean-time-between-failures determination as specified in the detail specification.

The wearout reliability determination is done in one of two ways: for simple hooks with only a fracture mode of failure and no applicable MTBF requirement, a "strength" test is used to reduce test times; for more complex hooks incorporating mechanisms having several possible failure modes, and having an MTBF as well as a wearout requirement, a "life" test is recommended.

### 2.9.3 Methods and Procedures

The following tests shall be conducted on each test article. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. For complex hooks having more than one mode of failure and an MTBF requirement as well as a wearout requirement, the test program shall be a "life" test, as defined in 1.2.2.3. For simple hooks with only a fracture mode of failure and no MTBF requirement, a "strength" test may be performed with "residual breaking strength" as the statistical parameter, as defined in Section 1.2.2.3.

#### 2.9.3.1 Functional Tests

Functional tests of the cargo hook assembly shall demonstrate satisfactorily all the functional features of the design, according to the requirements of the detail specification. A typical functional test cycle for releasable cargo hooks equipped with a swivel is:

- engagement of load (from zero to limit load)
- lift and hold for two minutes
- swivel  $\pm 150^\circ$  while loaded within specified torque
- release under specified mode
- relatch automatically
- swivel unloaded within specified torque.

#### 2.9.3.2 Emergency Release System Tests

When the means for emergency load release is nondestructive, the system shall be functionally tested concurrently with the other functional features. When this system is destructive, as with explosive bolts, a functional check is required only at the beginning of the test program and at the end of the environmental/endurance test. A dummy test setup may be used for these tests, if necessary, provided that the tested components were originally used in the hook assembly.

The test shall be conducted with a static load equal to 5% of rated static load. The emergency release system, including any redundant features, shall be actuated by the same means used in the aircraft installation. The system is acceptable only if all release devices function as designed.

#### 2.9.3.3 Proof Load

A static load equal to limit load shall be applied through each of the extreme load angles for a period of 5 minutes. There shall be no evidence of detrimental deformation as a result of this test.

#### 2.9.3.4 Pre-Endurance Tests

##### A. Rough Handling Test

All hooks shall be subjected to a rough handling test in the tumble box, shown in Figure 14, page 172, rotating at 15 rpm for 1 hour. Cable-mounted hooks shall be placed alone in the test box. Fixed hooks shall be fixed to one of the four sides of the box, using the same mounting points as on the aircraft. For large fixed hooks, 10,000 lb capacity or more, at least two shackles of the size normally used with that hook shall also be placed in the box. Smaller fixed hooks shall be tumbled with more shackles, enough to provide an impact almost every revolution, to a total of 6 on hooks of less than 1000 lb capacity. The orientation of the fixed hook in the tumble box shall be such as to accept the majority of shackle impacts on the forward end.

The test may be interrupted at any time for inspection of the test article. In the tumbling of fixed hooks, the engagement of the load beam with a shackle may be common; and when this is observed, by inspection or by a change in the noise level, the shackle shall be freed from the hook.

**B. Pre-Endurance Environmental Tests**

The remainder of the pre-endurance tests shall be conducted on each test article according to the applicable Sections of 1.1, Environmental Test Methods: 1.1.2.1 Vibration, 1.1.2.2 Fungus, 1.1.2.3 Sunshine, 1.1.2.4 Altitude, and 1.1.2.5 Fluid Damage Resistance. In addition, functional tests according to 2.9.3.1 shall be performed as required to monitor the effects of environments and at the conclusion of these tests.

Of these tests, sunshine, fungus, altitude, and fluid damage resistance may be deleted if the test article clearly will be unaffected by these environments, as stated, and justified, in the detail specification. Sunshine and fungus testing may be performed on representative material samples of the test article, except for nonmetallic structural members, which are sunshine tested full size prior to endurance. In either case, if the test produces adverse results, the environment(s) shall be added to the endurance test.

**2.9.3.5 Endurance/Environmental Tests**

- A. Each test item shall be subjected to endurance cycling and each of the tests listed under endurance tests in the schedule of test. The endurance cycle, the duration of the test, and the test conditions shall be determined by the requirements of the detail specification and Section 1.2, Experimental Test Design. The test program may be either a "strength" or a "life" test depending on the design of the test article and the requirement of the detail specification.

The test facility shall be capable of the same basic functions as that shown in Figure 16, page 175. Loading shall be accomplished by a loading cylinder or similar means capable of providing the test loads. The hook shall be mounted as on the aircraft - from a cable, or fixed. Provisions to operate the hook swivel under load shall be provided if applicable.

The endurance tests shall be based on typical use cycles such as the functional test of 2.9.3.1. The object of the endurance/environmental test shall be to demonstrate the MTBF requirement and/or the wearout reliability requirement(s) of the detail specification.

The endurance test may be accelerated using the procedures of Section 1.2.2.4, Test Acceleration Methods. For complex hook designs, the acceleration factor should not exceed two in order to avoid abnormal load paths or distortions. For simple hook designs, the test acceleration factor may be higher, provided that the S-N curve for the hook material is well-defined in the area of the accelerated load level.

Those aspects of functional testing not specifically covered in the endurance test cycle shall be periodically checked in order to monitor hook assembly performance.

Unless specifically deleted by the detail specification, the following environmental tests shall be combined with the endurance test loading program:

- Fluid damage resistance in accordance with Section 1.1.2.5
- Ice accumulation in accordance with Section 1.1.2.6
- Sand and dust in accordance with Section 1.1.2.7
- Salt fog in accordance with Section 1.1.2.8
- Extreme temperature in accordance with Section 1.1.2.9

- Temperature shock in accordance with Section 1.1.2.10
- Humidity in accordance with Section 1.1.2.11
- Immersion in accordance with Section 2.9.3.4B

The environment conditions shall be randomized with loading cycles according to Section 1.2.2.2, Randomization.

- B. All cargo hook assemblies with watertight compartments shall be subjected to an immersion test during the endurance test cycling. The hook assembly shall be submerged in water such that the entire external surface area is subject to a minimum hydrostatic pressure of 5 psig. The hook shall be submerged at random intervals during the endurance test a minimum of 10 times of 30 minutes duration each. If the hook has any moving parts, halfway through each immersion the parts shall be moved to introduce water into all areas possible.

#### 2.9.4 Accept/Reject Criteria

As outlined in Section 1.2.2.3, Reliability Test Methods, there are two basic types of test failures to consider: wearout and "chance" failures. The wearout criterion is to be applied to nonrepairable major structural or primary wearout failures. The "chance" failure criterion is to be applied to the less important repairable failures usually considered in determining an MTBF for the test article. The reliability requirements and confidence levels for each of these types of failures must be specified in the detail specification. The accept/reject decision, then, is based on the ability of the test article(s) to meet the reliability requirements of the detail specification.

Further causes for rejection are: damage or detrimental deformation in the proof load test, failure to meet functional test requirements at any time in the test program, and failure of any component of the emergency release system during the test program. Note that the reliability requirements for emergency release systems are generally much higher than that for the hook itself, due to the safety-of-flight consideration. It is generally much more practical to verify this reliability requirement on the component level where many samples can be tested, as outlined in Section 2.6, Emergency Release Devices. The inclusion of these devices in the hook assembly test is an opportunity to further check this reliability in a good simulation of service use, and any failure in this small sample would easily lower the estimate of the system's reliability below the detail specifications requirements.

## 2.9.5 Facilities Requirements

### 2.9.5.1 Rough Handling Box

The cargo hook assembly rough handling box is shown in Figure 14, page 172. The dimensions of the box shall be 8 ft by 8 ft by 4 ft deep. The interior of the box shall be steel plate with ten 3 in. by 3 in. by 4 in. iron angles on four sides as shown. The box shall be equipped with a drive system which will maintain a steady 15 rpm.

### 2.9.5.2 Endurance/Environmental Test Facility Requirement

A typical endurance/environmental test chamber is shown in Figure 16, page 175. Test facility requirements will vary between tests since qualification test requirements vary depending upon the hook design. The following is a list of all the facility requirements, some of which may be waived for a particular test program:

- A sand and dust circulation system
- A salt fog application system
- An environmental control system capable of providing the extreme temperature, humidity, and temperature shock atmospheres required.

- A hook loading system as shown in Figure 14 or equivalent. This may vary from a block of known weight to an automatically controlled system capable of a wide variety of loads, frequencies, and displacements.

#### 2.9.6 Detail Specification Requirements

The detail specification for the cargo hook assembly shall include the following provisions:

- A. Definition of the hook assembly and primary components
- B. Definition of functional requirements and operational cycle
- C. Specification of the design life spectrum and the design mission spectrum
- D. Specification of the life requirement and required confidence level on its substantiation
- E. Specification of the required wearout reliability and confidence level, and, for hooks with more than one failure mode, an MTBF requirement
- F. Specification of the limit load and extreme loading angles
- G. Specification of known environmental resistance characteristics of materials used in the construction of the hook
- H. Specification of fluid resistance requirements
- I. Specification of vibration test levels and test duration

#### 2.10 SLINGS

##### 2.10.1 Schedule of Tests

- (1) Proof Load
- (2) Rough handling
- (3) Fungus
- (4) Fluid Damage Resistance

- (5) Sunshine
- (6) Operational
- (7) Endurance-Environmental to include: Extreme Temperature, Rain, Humidity, Salt Spray, and Sand and Dust
- (8) Operational
- (9) Residual Breaking Strength

#### 2.10.2 Philosophy of Tests

Slings provide a convenient means of connecting material of almost any shape to a helicopter carrying point. The sling may be used in conjunction with a cargo hoist, a pendant, or an airframe hard point. The sling itself usually consists of multiple sling legs connected together at their upper end with a common apex fitting. A sling could, however, be as simple as a single leg. Many types of materials, both metallic and textile, are used in sling construction. Sling legs are commonly about 20 feet long and may have length adjustment features permitting adjustments of about 20 percent.

Slings suffer all the hostile environments of aircraft operation. Their service environment may be further complicated by the fact that they are usually stored on the ground, possibly under cover and possibly not. They are carted about in ground vehicles and may suffer more in this environment.

Because of the relatively large size of the deployed sling, testing may be more practical if carried out on separate sling legs and apex fittings. The scheduled tests encompass considerations for most common sling construction materials. It is probable that a specific sling design need not experience all scheduled tests because of previous knowledge of the selected material. In the case of a sling with legs fabricated from a relatively new textile and commercial steel oblong apex fitting ring, the test programs would be considerably different for the apex fitting and legs. The apex fitting might require only a proof load test, since much would be known about its ultimate strength and reaction to environments. The textile sling legs might well require all scheduled tests.

All tests except fungus tests shall be performed on full-scale test specimens, and the same test items shall be used throughout the program. Fungus tests can be performed on material samples, but they must be performed prior to endurance testing. Should fungus test results indicate that the material samples have been adversely affected, then the fungus environment must be included on the endurance-environmental test specimens prior to the start of endurance.

Operational tests of slings shall include any features offered, such as load attachment latches and length adjustments.

### 2.10.3 Methods and Procedures

The following tests shall be conducted on each test article. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. The test program is designed to be a "strength" test, with "residual breaking strength" as the primary statistical parameter as defined in Section 1.2.2.3.

#### 2.10.3.1 Proof Load Tests

##### (1) Sling Legs

All sling leg test specimens shall be subjected to a proof load test. The proof load shall be specified by the detail specification or, in the absence of a specified proof load, shall be 40 percent of the ultimate load requirement. Load shall be applied through the sling leg's production end fittings and shall be applied gradually. Proof load shall be maintained for a minimum of five minutes. At the conclusion of the proof test, the sling leg shall be examined for evidence of slippage, rupture, broken sewing thread, or frayed webbing. For many sling leg constructions, some permanent deformation is normal and should be anticipated.

(2) Apex Fittings

Proof load tests shall be similar to sling legs, except that the test shall be performed twice with sling leg loads applied at each extreme design angle (maximum and minimum spread of legs).

2.10.3.2 Rough Handling Test

All sling leg test specimens shall be tested in the test box shown in Figure 14, page 172, and described in Section 2.10.5. The sling leg shall be inserted in the box with its production end fittings. If an apex fitting is a part of the production configuration, the fitting shall be included. The box shall contain a dry aggregate of approximately 4 cubic feet of 2- to 3-inch, sharp-edged traprock (approximately 1 foot depth in a corner) and 1 cubic foot of masonry type sand. The test specimen and the aggregate shall be tumbled by rotating the box at 15 rpm for 1 hour. Upon removal of the sling leg, it shall be inspected for detrimental physical damage.

2.10.3.3 Fungus Test

At least one sling leg test specimen or apex fitting, or samples of all nonmetallic materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

2.10.3.4 Fluid Damage Resistance Test

All sling test specimens shall be subjected to a fluid damage resistance test in accordance with Section 1.1.2.5.

2.10.3.5 Sunshine Test

All sling test specimens shall be subjected to a sunshine test in accordance with Section 1.1.2.3.

2.10.3.6 Operational Tests

Operational tests shall be performed on all sling test specimens. These tests shall be designed to demonstrate any operational requirements which are secondary to the primary load-carrying function. Features such as load attachment latches and length adjustment devices shall be demonstrated.

### 2.10.3.7 Endurance-Environmental Test

- (1) The combined endurance-environmental test shall be performed in the test apparatus shown in Figure 16, page 175, and described in Section 2.10.5. The test loading and environment programs shall be constructed in accordance with the detail specification for the sling and the methods of Section 1.2, Experimental Test Design. The test program shall consider all of the operating parameters. These shall include:
  - load
  - load application rate
  - load duration
  - time unloaded
  - number of cycles of each load
  - environmental conditions
  - sling leg spread angle (for apex fittings)
- (2) The following environmental tests shall be combined with the endurance test loading program:
  - Extreme temperature test in accordance with Section 1.2.1.9
  - Rain test in accordance with Section 1.2.1.12
  - Humidity test in accordance with Section 1.2.1.11
  - Salt spray test in accordance with Section 1.2.1.8
  - Sand and dust test in accordance with Section 1.2.1.7
- (3) Periodic functional tests shall be scheduled in phase with the endurance test blocks to verify any operational requirements of the sling design. Example would be a check on the operation of any devices such as load attachment latches or length adjustment devices.

#### 2.10.3.7 Residual Breaking Strength Test

##### (1) Sling Legs

Tests shall be performed to determine the residual breaking strength of all test specimens. Load shall be applied through the sling leg's production end fittings at the maximum estimated design load application rate. Load shall be increased until the sling leg parts. The data shall be analyzed statistically to demonstrate that the residual breaking strength meets the reliability requirements at design limit load as shown in Section 1.2.2.3, Reliability Test Methods.

##### (2) Apex Fittings

Similar tests shall be performed on apex fittings. Sling leg loads on the fitting shall duplicate the number of legs in the sling design with loads applied at the maximum design sling leg spread angle.

#### 2.10.4 Accept/Reject Criteria

##### (1) Structural

The basic goal of the test program is to demonstrate the reliability requirement in the data obtained from the residual breaking strength data at the end of the test program. Any structural test result which will impair this goal earlier in the test program shall be reason for rejection of the pendant design. These may appear at any point during the test program should the test sling legs or apex fittings fail to react applied loads or show evidence of detrimental deformation. It should be noted that sling legs or apex fittings, especially in nonmetallic assemblies, may exhibit some permanent deformation as a result of high load application. This shall be acceptable, providing that the deformation does not impair its ability to perform its operational requirements.

(2) Operational

A sling design shall be considered rejected if the results of any test would make it fail to meet its operational requirements. An example of this would be a sling leg with a length adjustment feature which had become inoperable at any point in the test program.

2.10.5 Description of Facilities

(1) Proof Load and Residual Breaking Strength Facility

This facility must be capable of applying the required tensile loads at controllable rates. Sling legs will normally require a simple, direct, tensile load. For apex fittings, it is suggested that load be applied at the aircraft attachment point and reacted at adjustable, multiple attachment points to provide maximum and minimum sling leg spread angles for proof loading. Residual breaking strength will be determined at maximum spread angle.

(2) Rough Handling Facility

The rough handling facility utilizes the tumbling box illustrated in Figure 14, page 172. This provides random simulation of being dropped, dragged, or swung into hard objects. Additionally, abrasive and cutting actions resulting from being dragged are introduced with the sharp abrasive aggregate of traprock and masonry sand.

(3) Endurance-Environmental Facility

The endurance-environmental apparatus is pictured in Figure 16, page 175. Test environments shall be applied by the test chamber illustrated. The sling leg or apex fitting shall be installed in a manner similar to the sling leg shown in the inset to the figure. If the sling leg is long and upper and lower end fitting configurations are similar, only one end fitting and approximately 25 percent, or a minimum of 4 feet, need be exposed to the full environmental atmosphere. The tensile loading systems shall provide the capability of programming the test loads required by the

randomized load blocks. This will include load, load rate, and load duration. This can be as simple as a manually controlled hydraulic system for simple programs, or as complex as a completely automated cycling and loading system for major programs.

#### 2.10.6 Detail Specification Requirements

The detail specification for slings shall include the following provisions:

- (1) Definition of the design life, life spectrum loading, and mission spectrum requirements.
- (2) Specification of the wearout reliability requirement and confidence level on its verification.
- (3) Specification of limit load, proof load, and respective loading rates.
- (4) Specification of fluid resistance requirements.
- (5) Statement of established environmental resistance characteristics of materials used in pendant construction.
- (6) Specification for allowable sling leg angles relative to apex fitting.
- (7) Performance requirements for any features such as length adjustment devices on sling legs.

#### 2.11 NETS

##### 2.11.1 Schedule of Tests

- (1) Proof Load
- (2) Fungus
- (3) Fluid Damage Resistance
- (4) Sunshine
- (5) Endurance - Environmental to include: Extreme Temperature, Rain, Humidity, Salt Spray, and Sand and Dust
- (6) Residual Breaking Strength

### 2.11.2 Philosophy of Tests

Cargo nets are specialized cargo slings. They perform similar functions to slings but carry different types of materiel, usually awkward packages not easily contained by other methods. The schedule of tests is similar for nets and slings, but because of their differences in loading characteristics the test methods must be different.

For all cargo handling system components, an effort has been made in this report to specify combined endurance loading and environmental tests because the service component experiences simultaneous load and environment, and this is the best way to obtain their full interactions. Because of the size of the environmental facilities that would be required to test loaded full-size cargo nets, it is felt that practicality must modify this procedure. Endurance and environmental tests for nets can be performed separately, but each shall be divided into parts and the parts alternated to provide as much interaction possibility as practical.

Rough handling tests are not separately scheduled for nets but are conservatively introduced within the endurance test by providing an abrasive test surface for the net to set down on while relative motion is provided by swinging the net when elevated. The unloaded abrasive and cutting action of the rough handling tumble box used in other programs would be insignificant compared to the action of trapping the net between its load and a hard abrasive surface as it is set down. The test surface used will depend on the detail specification requirement or, in the absence of firm requirements, shall be sharp-edged traprock.

All tests except fungus tests shall be performed on full-scale test specimens, and the same test items shall be used throughout the program. Fungus tests can be performed on material samples but must be performed prior to endurance testing. Should fungus test results indicate that the material samples have been adversely affected, then the fungus environment must be included on the endurance-environmental test specimens prior to the start of endurance.

Cargo nets are generally picked up by a single suspension point. This point sees the total load within the net. For any given net load, the physical characteristics of the load within the net can greatly change the distribution of loading within the net structure. Test loadings should therefore be given careful consideration. It is required that the detail specification state the types of material that the net will be used to carry. It is conservative to assume that the load of highest density will provide the most severe net loading condition. The test loads can now be designed by selecting a material that will provide the approximate maximum density specified and a geometric shape that will provide the minimum corner radii that are anticipated in the material to be carried. Sizing of the units to make up the total test load should be based on the smallest package size among the materials listed.

The scheduled tests encompass considerations for nets made from any common construction materials, both metallic and textile. It is probable that a specific net design need not experience all scheduled tests providing justification can be given on the basis of previous knowledge or experience with the selected materials. Additionally, application information in the detail specification may negate or possibly add test requirements.

The following tests shall be conducted on each test article. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. The test program is designed to be a "strength" test with "residual breaking strength" as the primary statistical parameter as defined in Section 1.2.2.3.

#### **2.11.3.1 Proof Load Tests**

All net test specimens shall be subjected to a proof load test. The proof load shall be as specified by the detail specification or, in the absence of a specified proof load, shall be two-thirds of the ultimate load requirement. The net shall be loaded with a test load equal to proof load and then hoisted clear of the ground with a hoisting device. The loaded net shall be suspended for a minimum of 30 minutes. At the conclusion of the proof test, the net shall be examined for evidence of slippage, rupture, broken sewing thread, or frayed webbing.

#### 2.11.3.2 Fungus Test

At least one net test specimen or samples of all nonmetallic materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

#### 2.11.3.3 Fluid Damage Resistance Test

All net test specimens shall be subjected to a fluid damage resistance test in accordance with Section 1.1.2.5.

#### 2.11.3.4 Sunshine Test

All net test specimens shall be subjected to a sunshine test in accordance with Section 1.1.2.3.

#### 2.11.3.5 Endurance-Environmental Test

(1) The endurance-environmental test shall be performed in the test apparatus described in Section 2.11.5. The test loading and environmental programs shall be constructed in accordance with the detail specification for the sling and the methods of Section 1.2, Experimental Test Design. The test program shall consider all of the operating parameters. These shall include:

- total load, load density, and number and geometry of test load units
- hoisting rate
- load duration
- time unloaded
- number of cycles of each load
- environmental conditions
- relative ground speed at setdown

NOTE: When not otherwise specified, the relative ground speed at setdown shall be 10 feet per second peak velocity, and the ground surface shall be a 6-inch bed of 2- to 3-inch sharp-edged traprock.

- (2) The following environmental tests shall be alternated with the endurance test loading program, at the start and between at least four equal intervals of the load program:
- extreme temperature test in accordance with Section 1.2.1.9
  - rain test in accordance with Section 1.2.1.12.
  - humidity test in accordance with Section 1.2.1.11.
  - salt spray test in accordance with Section 1.2.1.8.
  - sand and dust test in accordance with Section 1.2.1.7.
- (3) Periodic functional tests shall be scheduled in phase with the endurance test blocks to verify any operational requirements of the net design. Example would be a check on the operation of any devices such as frame attachment hook keepers or length adjustment devices.

#### 2.11.3.6 Residual Breaking Strength Tests

All net test specimens shall be tested to determine the residual breaking strength at the end of the test program. Loading will commence at limit loads. The actual load at the lifting point shall be recorded. Test loads in the net will be increased in increments of 10 percent of limit load. At each increment, the net shall be lifted clear of the ground for not less than 1 minute. Residual breaking strength shall be the maximum load recorded prior to the net's failure to suspend all or part of the test loading units. The hoisting rate for these tests shall be the maximum estimated design load application rate. The data shall be analyzed statistically to demonstrate that residual strength meets the reliability requirements of design limit load as shown in Section 1.2.2.3, Reliability Test Methods.

#### **2.11.4 Accept/Reject Criteria**

The basic goal of the test program is to demonstrate the reliability requirement in the data obtained from the residual breaking strength data at the end of the test program. Any structural test result which will impair this goal earlier in the test program shall be reason for rejection at the net design. These may appear at any point during the test program should the test nets fail to react applied loads or show evidence of detrimental deformation. It should be noted that cargo nets, especially nonmetallic assemblies, may exhibit some permanent deformation as a result of high load application. This shall be acceptable, providing that the deformation does not impair its ability to perform its intended functions.

#### **2.11.5 Description of Facilities**

##### **(1) Test Loads**

Test loads, to be placed within the cargo nets during various loading phases of the test program, shall be designed to provide maximum test conservatism. The total load will be made up of loading units. The materiel used to make the test units shall be selected to provide a load density approximating the maximum load density of materiel to be carried in the nets. The shape and edge configuration of the units shall simulate the minimum radii expected in service loads. The size of the units shall be similar to the smallest package sizes anticipated in service.

##### **(2) Hoisting Facility**

Loaded test nets shall be lifted by a hoisting device installed in a suitable facility, such as the Hoist System Test Facility shown in Figure 13, page 171. The hoisting device shall be capable of providing adjustable hoisting rates up to the maximum estimated design rate. The facility shall also have provisions for swinging the elevated net to provide desired relative ground speed on contact. The ground surface below the net shall be prepared to produce the desired texture for endurance tests.

In the absence of specified ground contact conditions, it is suggested that the net be placed on a 6-inch-deep bed of 2- to 3-inch sharp-edged traprock and the loaded net be swung while elevated to produce a peak velocity of 10 feet per second.

#### 2.11.6 Detail Specification Requirements

The detail specification for cargo nets shall include the following provisions:

- (1) Definition of the design life, life spectrum loading, and mission spectrum requirements.
- (2) Specification of the wearout reliability requirement and confidence level on its verification.
- (3) Definition of the materiel to be carried by the net.
- (4) Definition of anticipated terrain characteristics where the net will be used.
- (5) Specification of allowable relative ground speed during net-ground contact.
- (6) Specification of limit load, proof load, and respective loading rates.
- (7) Specification of fluid resistance requirements.
- (8) Statement of established environmental resistance characteristics of materials used in net construction.

### 2.12 CONTAINERS, PALLETS, AND PODS

#### 2.12.1 Schedule of Tests

- (1) Product Inspection
- (2) Structural Proof Load Tests
  - (a) lifting load
  - (b) restraining load
  - (c) top (roof) proof load
  - (d) bottom (floor) proof load
  - (e) side and end wall proof load

(3) Rough Handling Tests

(a) free-fall drop tests

- (1) corner drop test
- (2) flat drop test

(b) tip-over test

(c) rotational drop test

- (1) edgewise
- (2) cornerwise

(d) impact tests

- (1) pendulum
- (2) incline

(e) superimposed load

(f) vibration

- (1) repetitive shock
- (2) sinusoidal shock

(4) Handling Characteristics Tests

(a) hoisting test

(b) assembly and disassembly demonstration

(c) lifting test

(d) towing test

(5) Environmental and/or Endurance Tests

2.12.2 Philosophy of Tests

This section covers those portions of the cargo handling system used to confine transported goods into a unitized mass to facilitate handling. These components shall be referred to as containers, pallets, and pods. For purposes of this document, the following definitions shall be adopted:

Container - An article of transport equipment:

- (a) designed to facilitate the movement of goods by one or more modes of transportation without intermediate reloading,
- (b) of permanent design strong enough for repeated use,
- (c) and fitted with devices permitting ready handling and transfer from one mode of transportation to another.

Large Container - Unless otherwise specified, large containers shall be considered as those which measure more than 60 inches on any edge or diameter or those which when loaded have gross weights in excess of 200 pounds.

Closed Van Container - Unless otherwise specified, closed van containers shall be considered as those closed containers which measure more than 10 feet in length.

Pallet - A portable, shallow container or platform for holding one or more units for storage or transport, intended to be handled mechanically as a single unit.

Pod - A specialized container designed for a specific cargo or mission and generally having a unique shape or configuration best suited for the cargo or mission.

It is recognized that there is a large range of types and complexities of cargo containers. A container may be almost any size or contour dependent upon aircraft space and weight limitations and the packaging requirements of the transported item, such as size, shape, weight, flexibility, fragility, anticipated loading, and required level of protection. Container construction may be of wood, metal, other materials or any combination of these which are considered practical and adequate for packaging requirements. Additionally, containers may be subjected to a variety of hostile environmental and handling conditions, including overloading, stacking, impact or dropping, vibration, rain, and corrosive fluids. For these reasons, the test guidelines presented in this section are of the most general nature, and each test shall apply only to those containers susceptible to the described test conditions.

The design of the test program for a specific container should include a review of all the tests listed in 2.12.1. The construction of a specific design may negate the requirement for some testing; for example, a steel pallet may be exempt from rain, sunshine, fungus, and humidity tests. It is recommended that all applicable scheduled tests be performed in the order stated on all test specimens. The schedule is designed to provide conservative assurance that the container will perform its design mission even though it has encountered rough handling and environment hazards along the way.

Since the size and expense of containers may be considerable, it is generally impractical, and usually not necessary, to perform an extensive reliability investigation as recommended for other cargo handling system components. At least one container of production configuration shall be tested and the same container used throughout the test program.

Product inspection is intended to show that the subject container conforms with the applicable detail specifications for design, material, workmanship, etc. These inspections are to check items such as: container material, construction, assembly, handling provisions, service and maintenance facilities, interchangeability, size, weight, finish, markings, identification, and workmanship.

Proof loading tests are designed to demonstrate that the container and its lifting and restraining provisions have sufficient strength to react resultant forces imposed on these structures during normal usage. These tests include provisions for accidental overloading and loading resulting from shifting of the container contents. Testing is performed to check the top (roof), bottom (floor), side, and end wall structures, and each means of lifting or restraining the container.

Rough handling tests are designed to simulate hostile handling conditions which may be encountered in service. These tests include simulation of accidental impact and dropping of the container, vehicle vibrations experienced during transport, and superimposed loading resulting from stacking and piling of containers.

Handling characteristics tests provide a demonstration of the assembly/disassembly procedure and the hoisting, lifting and towing design features incorporated into the container design.

Environmental and endurance tests are performed to simulate those hostile environments and endurance effects which may adversely affect the container performance. Many different environmental and environmental/endurance effects are possible, and the nature of the tests depends upon the type of container being tested.

### 2.12.3 Methods and Procedures

#### 2.12.3.1 Product Inspection

Product inspection shall be conducted to determine conformance with all detail specification requirements for strength, materials, design, surface finish, workmanship, etc. Guidelines for such inspections must be most general in nature due to the large range of container construction, material, mission requirements, etc. In effect, product inspection requirements for a particular container must be completely specified in the detail specification procuring such containers.

In the absence of inspection requirements in the detail inspection, the procedures of MIL-A-8421C "Air Transportability Requirements, General Specification For" or MIL-C-5584C "Containers, Shipping and Storage, Metal Reusable" shall be used for inspection guidelines.

#### 2.12.3.2 Structural Proof Load Tests

Structural proof load tests are performed to demonstrate that the container, when loaded to maximum gross weight, is capable of withstanding resultant forces imposed by the cargo on the container structural members. These tests are not required for every type of container; however, it is recommended that large containers and those containers whose contents are especially valuable or fragile be subjected to proof load tests. The test sample shall consist of at least one container representative of the production configuration.

##### 2.12.3.2.1 Lifting Tests

These tests are to provide substantiation of the container and its fittings subject to normal handling by slings, cables or other lifting equipment. The proof load shall be specified by the detail specification or, in absence of a specified proof load, shall be two times the container gross weight. Loading shall be according to the procedures of Section 7 of Basic Requirements for Cargo Containers, MH5.1-1970, published by the American National Standards Institute.

##### 2.12.3.2.2 Restraining Load Tests

These tests are to substantiate the container and its fittings subject to loadings resulting from container restraint during transport. The proof load shall be specified by the detail specification or, in the absence of a specified proof load, shall be 2.5 times the container gross weight applied longitudinally and/or 1.25 times the gross weight applied sideways. The procedures of Section 7 of Basic Requirements for Cargo Containers, MH5.1-1970, published by the American National Standards Institute, shall apply to these tests, unless otherwise specified by the detail specification.

2.12.3.2.3 Top (Roof), Bottom (Floor), Side, and End Walls  
Proof Loads

These proof loads shall be specified by the detail specification or, in the absence of a specified proof load, shall be:

- (a) A uniform loading of 250 pounds per square foot for the top or roof structure, except that this test shall not apply to areas with a curved or dome-shaped cross section.
- (b) A uniform loading 2.0 times the container gross weight for the bottom floor structure.
- (c) A uniform loading 0.4 times the container gross weight for the end wall structure.
- (d) A uniform loading 0.6 times the container gross weight for the side wall structure.

The procedures of Section 7 of Basic Requirements for Cargo Containers, MH5.1-1970, published by the American National Standards Institute, shall apply to these tests. However, methods using mediums other than water to impose loading on end and side walls may be substituted at the discretion of the test engineer. The use of air to produce loading equal to a fluid load is discouraged from a standpoint of safety. For containers not designed to be watertight, the tests may be conducted with dry loads.

In addition to a uniform static proof load, certain container floor structures such as crane-type cargo pods or closed van-type containers are subject to loadings more typically experienced by aircraft cargo compartment floor structures. These include concentrated loads, impact loads, and wheel and axle loads. For containers subject to such loads, unless otherwise specified in the detail specification, the procedures of Section 3.7.1.4.1 of SD-24K, Vol. 11, "Design and Construction of Aircraft Weapon Systems," shall apply to the concentrated and impact load test requirements.

The following procedure is recommended for the rolling load durability test.

A panel 18 inches square, supported at two edges, shall withstand a 500-pound rolling wheel load for 1000 complete cycles without undue surface wear or fatigue failure of the floor structure. An 8-inch-diameter steel wheel with a 2-1/2-inch radius is required for load application.

#### 2.12.3.3 Rough Handling Tests

Rough handling tests are performed to demonstrate that the container when loaded to maximum gross weight is capable of withstanding forces resulting from rough handling during transport. Not all rough handling tests are applicable for each type of container. It is therefore recommended that these tests be performed only on those types of containers considered, in the judgment of the test engineer, to be susceptible to the appropriate rough handling condition.

##### 2.12.3.3.1 Free-Fall Drop Tests

These tests demonstrate the ability of containers to withstand the impacts and the ability of the packaging and packing methods to protect the contents when the container is subjected to free-fall drops when fully loaded as specified.

- Corner Drop Tests - Unless otherwise specified in the detail specification, Procedure E of Method 5007 of the Federal Test Method Standard No. 101B shall apply to these tests.
- Flat Drop Tests - Unless otherwise specified in the detail specification, the flat drop test shall be conducted according to Procedure B of Method 5007 of the Federal Test Method Standard No. 101B.

##### 2.12.3.3.2 Tip-Over Test

This test is meant to simulate the impacts of accidentally tipping over a container and to demonstrate sufficient container strength to protect the contents when tipped over. Unless otherwise specified in the detail specification, the procedure of Method 5018 of Federal Test Method Standard No. 101B shall apply to these tests.

#### 2.12.3.3.3 Rotational Drop Tests

These tests are to simulate the impacts of accidentally dropping a container on its corners or edges to demonstrate sufficient container strength when so dropped.

- Cornerwise Test - Unless otherwise specified in the detail specification, such containers shall be subjected to a cornerwise drop test in accordance with the procedures of Method 5005 of the Federal Test Method Standard No. 101B.
- Edgewise Test - The edgewise rotational drop test shall be performed according to the procedures of Method 5008 of the Federal Test Method Standard No. 101B, unless otherwise specified in the detail specification.

#### 2.12.3.3.4 Impact Tests

These tests are meant to simulate accidental handling impacts to demonstrate the ability of the container to provide sufficient protection to the contents during such conditions.

Unless otherwise specified in the detail specification, the impact tests shall be performed in accordance with the procedures of Method 5012 and Method 5023 of the Federal Test Method Standard No. 101B for pendulum and incline type impact tests respectively.

#### 2.12.3.3.5 Superimposed Load

These tests are designed to simulate the superimposed loads resulting from stacking of like containers or piling of many small, heavy packages on a container.

In the absence of a specific procedure in the detail specification, the superimposed loads tests shall be performed in accordance with the procedures of Method 5016 and/or Method 5017 of the Federal Test Method Standard No. 101B, except that to avoid unrealistically high loads, the method of calculating the applied load in Method 5016 shall be modified as follows. Each container shall be subjected to a load equivalent to two similar containers (with contents) in a superimposed

position, or a number of containers (with contents) stacked to a height of 16 feet, whichever is greater.

#### 2.12.3.3.6 Vibration

These tests are intended to indicate whether or not a container is adequate to prevent damage to those contents that might be susceptible to vibration encountered during transport.

- Repetitive Shock - This procedure is useful to predict whether or not such vibrations in transport are likely to cause damage to the container or contents when the shipment is not securely tied to the floor of the vehicle. Unless otherwise specified in the detail specification, the repetitive shock test shall be performed in accordance with the procedures of Method 5019 of the Federal Test Method Standard No. 101B.
- Sinusoidal Motion - This method simulates the probable shipping vibration environment of containers that are secured to the floor of the carrier in transit. Method 5020 of Federal Test Method Standard No. 101B shall apply unless otherwise specified in the detail specification.

#### 2.12.3.4 Handling Characteristics Tests

Handling characteristics tests are performed to demonstrate that the fully loaded container meets the design requirements for handling during transfer and transport. These tests include hoisting, lifting, towing, and assembly and disassembly of the container utilizing those design features incorporated into the container design to facilitate such handling. Each test described in this section may or may not be applicable to each type of container, and therefore it is recommended that these tests be performed only on those containers subject to the appropriate test condition.

#### 2.12.3.4.1 Hoisting Tests

Hoisting tests demonstrate the capability of the container to be lifted free of the ground by each of the design-specified suspension provisions. Unless otherwise specified in the detail specification, the hoisting tests shall be performed in accordance with the procedure of MIL-C-5584C, "Containers, Shipping and Storage, Metal, Reusable."

#### 2.12.3.4.2 Assembly and Disassembly

This test shall demonstrate the assembly/disassembly procedure, the tools required, and the man-hours consumed. The procedure of MIL-C-5584C, "Containers, Shipping and Storage, Metal, Reusable," shall apply unless otherwise specified.

#### 2.12.3.4.3 Lifting Tests

The lift test demonstrates the capability of the container to be lifted and transported by fork-lift truck. The procedure of MIL-C-5584C, "Containers, Shipping and Storage, Metal, Reusable," shall apply unless otherwise specified in the detail specification.

#### 2.12.3.4.4 Towing Test

The towing test demonstrates the capability of the container to be towed using the towing hooks, rings, or eyes provided. Unless otherwise specified in the detail specification, the procedure of MIL-C-5484C, "Container, Shipping and Storage, Metal, Reusable," shall apply.

#### 2.12.3.5 Environmental/Endurance Tests

Because of the recognized wide range of container type, construction, materials, cargo, mission requirements, etc., the guidelines for both environmental and endurance test requirements must be most general. In effect, the detail specification for the container in question specifies any requirements for environmental, endurance or environmental/endurance tests through the specification of functional requirements and expected use conditions. Those environmental and/or endurance procedures listed in Sections 1.1 and 1.2, respectively, shall be applied as applicable.

For example, an aluminum container with a neoprene gasket might be subject to rain, salt spray, fungus, and fluid resistance tests of the gasket material. A personnel pod with a functional doorway might be exempt from the above tests but subject to an endurance and sand and dust test of the doorway.

#### 2.12.3.5.1 Leakage Test

For those containers intended to provide water and vaporproof protection during shipping and storage, a leakage test shall be required. Unless otherwise specified in the detail specification, the leakage test shall be performed in accordance with the procedures of MIL-C-5584C, Containers, Shipping and Storage, Metal, Reusable."

For those containers classified as closed van containers, the weatherproofness test procedure of MH5.1-1970 "Requirements for Closed Van Containers," published by the American National Standards Institute, shall apply in absence of a detailed leakage test specification.

#### 2.12.4 Accept/Reject Criteria

Accept/reject criteria must be completely specified in the detail specification for the container in question. In the absence of detailed accept/reject criteria, the criteria specified in the appropriate test procedure (if any) and/or the general criteria of Section 3.8 of MIL-C-5584C, "Containers, Shipping and Storage, Metal, Reusable," shall be applicable. Simply stated, the container and all essential accessories shall reveal no structural weakness that will prevent ready disassembly, assembly, and reuse of the container following testing.

#### 2.12.5 Description of Facilities

##### (1) Proof Load, Rough Handling, and Handling Characteristics Tests

No special test facilities are required for most of these tests. The required apparatus and test setups are adequately described in the appropriate test procedures.

Should the container in question require a special test setup or facility, the detail specification for that container must completely describe these requirements.

(2) Environmental and/or Endurance Tests

Test facilities requirements for environmental and/or endurance tests will depend upon the type of test and the specific test requirements. It is therefore recommended that the detail specification for procurement of the container in question completely specify all requirements for test facilities for environmental and/or endurance testing.

2.12.6 Detail Specification Requirements

The detail specification for containers, pallets, and pods shall include the following provisions:

- A. Definition of the container requirements including size, material, construction, design loads, operational features, weight, expected use conditions, and methods of handling.
- B. Specification of any special or unusual test procedure.
- C. Specification of the required inspection.
- D. Specification of the required proof loads.
- E. Specification of the accept/reject criteria.
- F. Specification of the fluid resistance requirements.
- G. Statement of established environmental resistance characteristics of materials used in container construction.

## 2.13 ROLLERS AND SHEAVES

### 2.13.1 Schedule of Tests

#### (1) Product Inspection

- (a) Eccentricity
- (b) Wobble Clearance (sheaves only)

#### (2) Static Loads

- (a) Proof Load
- (b) Bond Strength
- (c) Flange Strength
- (d) Static Friction Torque

#### (3) Environmental and Endurance - Environmental

- (a) Fungus Test
- (b) Sunshine Test
- (c) Fluid Damage Resistance Test
- (d) Endurance/Environmental - to include:  
Extreme Temperature, Rain, Humidity,  
Salt Spray, and Sand and Dust

### 2.13.2 Philosophy of Tests

This section deals with those portions of the cargo handling system generally used to facilitate the loading and unloading of cargo. These components are rollers and sheaves. Rollers are defined as small wheels or cylinders over which the material is rolled into and out of the aircraft. Sheaves are small wheels with grooved rims used with winching systems to change the direction and application of the applied force and, when combined in blocks, to increase the magnitude of the applied force.

There is a recognized wide range of size and type of rollers and sheaves. Construction may be of metal, wood, fiberglass, phenolic, or other material considered practical and adequate to meet design requirements. Additionally, rollers and sheaves may be subjected to a variety of service use and hostile environment conditions, including overload, undue friction, angle of pull, condition of cable, sudden application of load, lack of lubricant, twisted cable or improper reeving, moving of heavy loads over rough ground or an incline, or without rollers or too small rollers, sand and dust, salt spray, aircraft fluids, and extreme temperature. For these reasons, the test guidelines presented in this section are of the most general nature, and the detail specification for the roller or sheave in question shall completely specify the appropriate test conditions.

The design of the test program for a specific roller or sheave should include a review of all of the tests listed in 2.13.1. The construction of a particular design may negate specific test requirements; for example, a stainless-steel roller may be exempt from fungus testing. It is recommended that all applicable scheduled tests be performed in the order stated on all test specimens except that the static friction torque test be performed first on each test specimen. This shall ensure that no previous testing has affected the bearing friction characteristics. Fungus tests can be performed on a material sample, and they must be performed prior to endurance testing. Sunshine and fluid damage resistance tests shall be performed on the endurance test specimens prior to the start of endurance testing. Thus, the order of testing will expose the endurance test specimens to these tests prior to endurance. The results of these tests might not appear significant by themselves but may interact later with the environmental endurance tests to reveal a deficiency.

### 2.13.3 Methods and Procedures

The following tests shall be conducted on each test article. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability and endurance requirements of the detail specification. The test program is designed to be a "life" test as defined in Section 1.2.2.3.

#### 2.13.3.1 Product Inspection

Product inspection shall be performed to demonstrate conformance with the detail specification with respect to dimensions, tolerance, weight, finish, lubrication, identification of product, and workmanship. Included in this inspection shall be checks of both eccentricity and wobble clearance of the subject rollers or sheaves.

##### 2.13.3.1.1 Eccentricity

The eccentricity of the rolling surface (for rollers) and the periphery of the groove and groove flanges (for sheaves) shall be checked with respect to the longitudinal axis of the bearing in such a manner that the bearing clearance is not included as eccentricity. The roller (sheave) shall be securely held in a suitable fixture and the eccentricity measured while the roller or sheave is rotated through one revolution.

##### 2.13.3.1.2 Wobble Clearance (sheaves only)

The clearance between the sheave and a plane which is perpendicular to the bearing longitudinal axis, and which contacts the end of the bearing inner race, shall be checked in the following manner. The inner bearing race shall be secured in a suitable jig and the specified limit load applied with 180 degrees of cable wrap and the specified pulloff angle. The minimum clearance between the plane surface and the sheave flange shall be determined by placing the load at various positions about the complete circumference of the sheave. The test shall be repeated with the sheave inverted.

#### 2.13.3.2 Static Loads

##### 2.13.3.2.1 Proof Load

All roller and sheave test specimens shall be subjected to a proof load test to demonstrate sufficient strength to react an accidental overload. The proof load magnitude shall be equal to the design limit load or two-thirds of the ultimate load requirement, whichever is larger.

The roller or sheave shall be positioned in a test fixture in such a manner as to permit rotation. The load shall be applied by means of an appropriate pressure plate contacting the sheave or roller through an angle of wrap or contact as specified in the detailed specification. The maximum load shall be maintained for not less than 5 minutes, during which the roller/sheave shall not have side support from the jig. At the conclusion of the proof test, the sheave or roller shall be examined for evidence of buckling, splitting, or other types of failure. Failure of the bearings shall not constitute failure of the subject roller or sheave for this test.

#### 2.13.3.2.2 Bonding Strength

Bonding strength tests shall be performed to demonstrate sufficient bond strength between the roller or sheave and the bearing. The bond strength load must be specified in the detail specification for procuring the subject roller or sheave.

The roller or sheave shall be supported in a suitable jig with the bearing unsupported and free to be pushed out of the roller or sheave in case of failure. The specified load shall be applied gradually to the inner race of the bearing along the bearing longitudinal axis. The maximum load shall be maintained for not less than 30 seconds. The test shall be repeated with the roller or sheave inverted. At the conclusion of the bonding test, the roller or sheave shall be examined for evidence of loosening, separation, shifting of the bearing, or other evidence of roller or sheave failure.

#### 2.13.3.2.3 Static Friction Torque

Measurements of the static friction torque of the bearing shall be obtained to demonstrate that the roller or sheave meets friction torque requirements when tested under no load and under design limit load. The friction torque requirements shall be specified in the detail specification for procuring the subject rollers or sheaves.

The specimen shall be rotated manually for approximately 15 seconds to ensure sufficient agitation of the contained lubricant to permit testing with uniform lubricant consistency. The roller or sheave shall then be mounted in a suitable jig in such a manner as to permit rotation of the outer race of the bearing. With no load applied to the roller or sheave, a torque of sufficient magnitude to cause rotation shall be applied to the outer race of the bearing. This load is used to determine the static friction torque value of the roller or sheave at no load. This torque shall not exceed the value given in the detail specification for the particular roller or sheave. With the limit load applied to the roller or sheave, a torque of sufficient magnitude to cause rotation shall be applied to the outer race of the bearing. This load is used to determine the static friction torque of the roller or sheave at the limit load. This torque shall not exceed the value specified in the detail specification for the particular roller or sheave. This test shall be performed on rollers and sheaves prior to any other tests.

#### 2.13.3.2.4 Flange Strength Tests (sheaves only)

Each sheave test specimen shall be subjected to a flange strength test to demonstrate sufficient strength to resist checking or shearing. The flange load shall be specified in the detail specification for the particular sheave. The pulley shall be rigidly clamped in a jig. The specified load for the particular sheave under test shall be applied to the inside of the flange perpendicular to the plane of the pulley, through the loading block in line with the root diameter. The maximum load shall be maintained for not less than 30 seconds. Both flanges shall be tested, the load being applied to one flange 90 degrees from its application point on the second flange. Following loading, the sheave shall be examined for evidence of checking, splitting, shearing, or other types of failure.

**2.13.3.3      Environmental and Environmental/Endurance Tests**

**2.13.3.3.1    Fungus Tests**

A test roller or sheave or samples of all non-metallic roller or sheave materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

**2.13.3.3.2    Sunshine Test**

Roller or sheave test specimens or samples of roller or sheave materials shall be subjected to a sunshine test according to the procedures of Section 1.1.2.3.

**2.13.3.3.3    Fluid Damage Resistance Test**

All roller and sheave specimens shall be tested in accordance with Section 1.1.2.5 to demonstrate their resistance to the damaging effects of the listed fluids.

**2.13.3.3.4    Environmental/Endurance Tests**

(1) A combined environmental/endurance test shall be performed on each test article in accordance with the loading and environmental requirements of the detail specification for the subject roller or sheave and the guidelines of Section 1.2, Experimental Test Design. Due consideration must be given to all of the operating parameters. These shall include:

- load
- number of revolutions at each load
- number of load reversals
- cable wrap angle (sheaves)
- maximum allowable wear
- environmental conditions

(2) The following environmental conditions shall be combined and randomized with the endurance test program:

- sand and dust in accordance with Section 1.1.2.7
- salt spray in accordance with Section 1.1.2.8

- extreme temperature in accordance with Section 1.1.2.9
- humidity in accordance with Section 1.1.2.11
- rain in accordance with Section 1.1.2.12

(3) Periodic checks of roller or sheave for wear, static friction torque, bonding strength, and wobble clearance (sheaves only) shall be scheduled in phase with the endurance test blocks to verify that the subject roller or sheave meets these detail specification requirements. A roller or sheave shall be considered to have failed when any of the above requirements are not met, either during the test or at the conclusion of the test.

#### 2.13.4 Accept/Reject Criteria

A roller or sheave shall be considered rejected if the results of any test demonstrate that it fails to meet the detail specification requirements for that particular test.

#### 2.13.5 Description of Facilities

##### 2.13.5.1 Eccentricity Test Facility

This test fixture must be capable of securely holding the bearing inner race while the pulley or roller is rotated and the eccentricity checked.

##### 2.13.5.2 Proof Load, and Friction Torque Test Facility

This jig shall secure the test roller or sheave in such a manner as to permit rotation but not provide side support to the test article. Loading shall be introduced by a cable (sheaves) or a plate (rollers) in such a manner that the sheave or roller is loaded across the contact arc specified in the detail specification.

#### **2.13.5.3     Environmental/Endurance Test Facilities**

The endurance/environmental chamber for sheaves shall be similar to the test facility shown in Figure 15, page 173. The chamber shall be capable of applying the environments as required in the test plan, in a manner similar to that shown in Figures 12, page 169, and 16, page 175. The rotary motion device shown in Figure 15, page 173, may impart oscillatory motion or continuous rotation as required by the test plan. When continuous rotation is used, a single test cable with a small connector, suitable for passage over the test sheaves, shall be used.

The endurance/environmental test facility for rollers is shown in Figure 18, page 179. The chamber shall be capable of applying the environments as specified in the test plan, in a manner similar to that shown in Figures 12, page 169, and 16, page 175. The speed and throw of the eccentric, and the test weight, shall be adjusted to meet the requirements of the test plan.

#### **2.13.5.4     Flange Strength Test Facility**

This facility may be similar to that shown in Figure 6 of MIL-P-7034B, "Pulleys, Groove, Antifriction-Bearing, Grease Lubricated, Aircraft."

#### **2.13.6        Detail Specification Requirements**

The detail specification for rollers or sheaves shall include the following provisions:

- A. Definition of the design and specific design requirements such as: allowable eccentricity, allowable sheave wobble clearance, cable wrap angle or roller contact angle, bond strength load, no-load friction torque, limit load friction torque, sheave flange strength load, and sheave cable pulloff angle.
- B. Specification of endurance requirements such as: load life spectrum, cable or pallet speed, reversal requirements, cable wrap angle, allowable wear, and design life.

- C. Statement of established environmental resistance characteristics of materials used in roller or sheave construction.
- D. Specification of fluid resistance requirements.
- E. Specification of limit load.
- F. Specification of wearout reliability and the confidence level on its verification.

## 2.14 CARGO RESTRAINTS

### 2.14.1 Schedule of Tests

- (1) Proof Load
- (2) Rough Handling Test
- (3) Fungus
- (4) Fluid Damage Resistance
- (5) Environmental, to include: Extreme Temperature, Rain, Humidity, Sunshine, Salt Spray, and Sand and Dust
- (6) Residual Breaking Strength

### 2.14.2 Philosophy of Tests

Cargo restraints shall include any devices such as cargo tie-down straps, cargo restraining nets, and their associated hardware, hooks, length adjustment features, and pretensioning devices. Cargo restraining devices are both handy and essential tools and, as a result, are used for a variety of applications all around aircraft operations.

Their usage exposes them to all of the environments experienced in normal flight operations and ground support of these operations. They are used internal to the aircraft fuselage and, just as frequently, external to the aircraft.

The schedule of tests shall, therefore, include tests of the restraints' ability to resist all types of environmental extremes. Working loads on cargo restraints are generally very low in respect to their ultimate strength capability. This is by design, since the load required to restrain cargo is very low under normal operating conditions.

The restraints, however, must be designed to restrain the cargo under very severe conditions, such as crash conditions. Most restraints never see these larger loads during their operational life. Since operating life is not a function of load, an endurance test is excluded from the test schedule. The restraints must, however, demonstrate the strength with an initial proof test, be exposed to all environmental extremes, and exhibit residual strength following exposure.

Restraint hardware, hooks, length adjustment devices, and pretensioning features need not be separately tested, but shall experience all the test environments and demonstrate adequacy in structural tests.

All tests except fungus tests shall be performed on full-scale test specimens, and the same test item shall be used throughout the program. Fungus tests can be performed on material samples, but they must be performed prior to residual strength testing. Should fungus test results indicate that the material samples have been adversely affected, then the fungus environment must be included on the residual breaking strength test specimens. The scheduled tests encompass considerations for restraints made from any common construction materials, both metallic and textile. It is probable that a specific design need not experience all scheduled tests, providing justification can be given on the basis of previous knowledge or experience with the selected materials. Additionally, design mission information in the detail specification may negate or possibly add test requirements.

#### 2.14.3 Methods and Procedures

The following tests shall be conducted on each test article. The number of test articles shall be determined according to the provisions of Section 1.2.2.3, Reliability Test Methods, and the reliability requirements of the detail specification. The test program is designed to be a "strength" test with "residual breaking strength" as the primary statistical parameter as defined in Section 1.2.2.3.

#### 2.14.3.1 Proof Load Tests

All restraint test specimens shall be subjected to a proof load test. The proof load shall be as specified by the detail specification or, in the absence of a specified proof load, shall be two-thirds of the ultimate load requirement.

##### (1) Tie-Down Straps

Cargo tie-down straps shall be tested in a manner similar to sling legs, Section 2.10.3.1(1).

##### (2) Cargo Restraining Nets

Nets shall be tested by placing the net over simulated cargo and loading tie-down points or, if geometry permits, supporting the net on a frame at the tie-down points and loading in a manner similar to cargo nets, Section 2.11.1.

#### 2.14.3.2 Rough Handling Test

Restraint assemblies shall be tested in the test box shown in Figure 14, page 172, and described in Section 2.14.5. The restraint shall be inserted in the box with its production end fittings. If a hook is a part of the production configuration, the hook shall be included. The box shall contain a dry aggregate of approximately 4 cubic feet of 2- to 3-inch sharp-edged traprock (approximately 1 foot depth in a corner) and 1 cubic foot of masonry type sand. The test specimen and the aggregate shall be tumbled by rotating the box at 15 rpm for 1 hour. Upon removal of the restraint, it shall be inspected for detrimental physical damage. The integrity or operation of any hook keepers, length adjustment devices, and pretensioning devices shall be verified.

#### 2.14.3.3 Fungus Test

A test restraint or samples of all nonmetallic materials shall be subjected to a fungus test in accordance with Section 1.1.2.2.

#### 2.14.3.4 Fluid Damage Resistance Test

All restraint specimens shall be subjected to a fluid damage resistance test in accordance with Section 1.1.2.5.

#### 2.14.3.5 Environmental Exposure

(1) The following environmental tests shall be performed:

- Extreme temperature test in accordance with Section 1.1.2.9
- Rain test in accordance with Section 1.1.2.12
- Humidity test in accordance with Section 1.1.2.11
- Sunshine test in accordance with Section 1.1.2.3
- Salt spray test in accordance with Section 1.1.2.8
- Sand and dust test in accordance with section 1.1.2.7

(2) Periodic functional tests shall be scheduled in phase with the environmental tests to verify any operational requirements of the restraint design. Example would be a check on the operation of hook keepers, length adjustment devices, and pretensioning devices.

#### 2.14.3.6 Residual Breaking Strength

All restraints shall be tested to determine residual breaking strength at the end of the test program. Loading methods shall be similar to proof loading methods, Section 3.14.3.1. The strength data shall be analyzed statistically to demonstrate that residual strength meets reliability requirements of design limit load as shown in Section 1.2.2.3, Reliability Test Methods.

#### 2.14.4 Accept/Reject Criteria

##### (1) Structural

The basic goal of the test program is to demonstrate the reliability requirements in the data obtained from the residual breaking strength data at the end of the test program. Any structural test result which will impair this goal earlier in the test program should the test pendants fail to react applied loads, show evidence of detrimental deformation, exhibit broken strands, fiber, or sewing threads, or suffer excessive abrasion shall be cause for rejection. It should be noted that restraints, especially nonmetallic assemblies, may exhibit some permanent deformation as a result of high-load application. This shall be acceptable, providing that the deformation does not impair its ability to fulfill its operational requirements.

##### (2) Operational

A restraint design shall be considered rejected if the results of any test would make it fail to meet its operational requirements. An example of this would be a tie-down strap with a length adjustment feature or pretensioning device which had become inoperative at any point in the test program.

#### 2.14.5 Description of Facilities

##### (1) Proof Load and Residual Breaking Strength Facility

This facility must be capable of applying the required tensile loads at controllable rates.

##### (2) Rough Handling Facility

The rough handling facility utilizes the tumbling box illustrated in Figure 14, page 172. This provides random simulation of being dropped, dragged, or swung into hard objects. Additionally, abrasive and cutting actions resulting from being dragged are introduced with the sharp abrasive aggregate of traprock and masonry sand.

(3) Environmental Facility

Test chambers and facilities shall be used as required in Section 1.1, Environmental Test Methods. Test chambers of sufficient size to handle the restraint test articles are commercially available.

2.14.6 Detail Specification Requirements

The detail specification for cargo restraints shall include the following provisions:

- (1) Specification of the "wearout" reliability requirement and confidence level on its verification.
- (2) Definition of the material to be restrained.
- (3) Specification of limit load, proof load, and respective loading rates.
- (4) Specification of fluid resistance requirements.
- (5) Statement of established environmental resistance characteristics of materials used in net construction.

### **3. SYSTEM TEST METHODS**

#### **3.1 HOIST AND WINCH SYSTEMS**

##### **3.1.1 Schedule of Tests**

The hoist/winch system shall be subjected to the following tests:

##### **3.1.1.1 Pre-Endurance**

- Functional No-Load
- Partial and Full Load
- Side Loads
- Loaded Cable Releases
- Alternate Drive Operation
- Malfunction Safety Functions
- Sunshine

##### **3.1.1.2 Endurance/Environmental Tests**

- High Temperature in accordance with Section 1.1.2.9A
- Temperature Shock in accordance with Section 1.1.2.10
- Low Temperature in accordance with Section 1.1.2.9B
- Ice Accumulation in accordance with Section 1.1.2.6
- Rain in accordance with Section 1.1.2.12
- Humidity in accordance with Section 1.1.2.11
- Salt Fog in accordance with Section 1.1.2.8
- Sand and Dust in accordance with Section 1.1.2.7

### 3.1.2

#### Philosophy of Tests

The term "cargo hoist" refers to the device which lifts a load vertically, generally by means of a cable and drum. A "winch" is a device that pulls a cable horizontally with no gravity-dependent functions, although the use of pulleys in the winch system can make the distinction between a hoist and a winch quite arbitrary. Winches often do not incorporate a brake, to allow control of paying-out of cable, but a hoist system almost always incorporates this feature. Another distinction is made with a "positioning" hoist, a device which can support a load but not change the hook position while loaded. This device is covered in Section 3.2.

The tests recommended here are system-level tests, component-level tests already having been accomplished on all of the devices used in the hoist or winch system. The hoist or winch itself receives only a limited component test (Section 2.3), which normally would not include an endurance/environmental test. The goals of the system-level tests, then, are: to assure that the demonstrated performance of the individual system component is not compromised when used in the hoist/winch system; to complete an endurance/environmental test of design life duration without failure of any major system component; and to demonstrate the required system MTBF.

The test article shall be a pre-production sample of the hoist/winch assembly, including motive drive and isolation devices. The test system shall consist of the hoist/winch assembly connected to the motive drive power source and all operational support systems, including their controls and instruments, through aircraft lines and interface connections.

The test program recommended here for hoist/winch systems is a compromise from an "ideal" approach, which would be prohibitively expensive and time-consuming. The ideal approach would be to apply rigorously the provisions of Section 1.2.2.3, Reliability Test Methods, for both the "Wearout" and "Chance Failure" criteria.

Although the chance failure, or "Mean-Time-Between-Failures", requirement of the detail specification can usually be demonstrated in a reasonable test program, any reasonable wearout requirement usually means a very long test program. A more practical approach is to require that all primary components and parts of the hoist/winch system be free from major nonrepairable structural or wearout failure for a period of time equal to the system design life. This requirement can be met with one sample if there are no serious development problems. If a part fails and a redesign is undertaken, the redesigned part must be tested for one design life. Depending on the time of failure and the testing costs, the testing of the first test article, incorporating the design change, may be extended beyond the design life, or a second test article may be started at zero time on all parts. The MTBF test requirement can generally be met within the test durations required for this wearout program.

Although the recommended test program does not meet rigorous reliability criteria for wearout, it is considered adequate for the following reasons:

- The endurance/environmental test program is inherently conservative, representing all extremes of operation. Few hoists or winches would be expected to see this in service.
- Parts of the system will actually be subjected to a test duration longer than design life, due to the development nature of prototype testing.
- Production runs of hoists or winches are usually small, and a rigorous test program would often require more samples than would fail in service.

In hoist system testing, the importance of the effects of gravity cannot be overemphasized. The use of a vertical-suspension test facility, such as shown in Figure 13, 171, is mandatory in hoist system test programs. No other method can practically duplicate the acceleration-deceleration forces imposed on a cargo hoist in operation, that is, no one has found a good substitute for gravity.

One part of a hoist system receives special attention. As outlined in Section 2.4, load isolators often require extensive dynamic testing, which is usually not feasible, or necessary, on the system level. Load isolators, then, receive a comprehensive dynamic response and endurance test on the component level, based on the analytically predicted dynamic characteristics of the aircraft and load system. On the system level, the load isolators are again subjected to endurance testing, but of a different nature, since step input "lifting" cycles differ from the steady-state dynamic inputs of airframe vibration. Finally, when a flight test vehicle is available, the predicted dynamic characteristics of the hoist system are compared to the actual characteristics.

### 3.1.3 Methods and Procedures

The test system requirements are grouped into two basic categories:

- (a) Pre-Endurance
- (b) Endurance/Environmental

#### 3.1.3.1 Pre-Endurance Tests

The functional test shall be conducted on the test article described in 3.1.2 installed in the test facility of 3.1.5. The functional tests of Sections 3.13.1.1 and 3.13.1.2 shall be conducted after each pre-endurance test to demonstrate no degradation of performance.

##### 3.1.3.1.1 Functional No-Load Tests

The unloaded hoist/winch will be operated to ascertain that all functions of the system perform satisfactorily. Under no load, the system shall be operated in all normal modes, utilizing all control inputs, to demonstrate functional characteristics of all limit switches, stow override controls, hook release, and all associated monitoring and indicating subsystems such as cable length or load, travel limit actuation indication, override actuation, or any remote advisory indications normally intended to be monitored by the aircraft crew.

The hoist/winch shall be operated through a cable travel of at least 60% of the cable length with no stops from the reeled-out position to the extreme reeled-in position and then returned to the reeled-out position. The cycle shall then be repeated with random stops during both the reeling in and out modes of the cycle. Winch cables may be assisted in reeling out only to the extent that cable may be moved away from the winch by hand to prevent tangling or fouling.

If the hoist/winch speed is controllable, operate the system from minimum to maximum speed at each of the test conditions specified.

#### 3.1.3.1.2 Partial- and Full-Load Operation

With loads in at least four increments up to rated load, operate the hoist/winch from the extended cable length to the fully reeled-in position using the cable travel limiting device, if incorporated, to stop the hoist or winch operation. Reel out the cable under each cable load to the fully extended position. Conduct a cycle with no intermediate stops in either direction, followed by a cycle with random stops and direction reversals in both the reel-in and reel-out modes.

Any system functions which normally would be performed during aircraft operation of the hoist/winch system shall be simulated in the normal operating sequence relative to the cable load application test.

All monitoring or measuring system accuracies shall be established at each load and speed condition, and the effect of interaction determined. System power requirements at each load condition shall be measured and efficiencies established.

#### 3.1.3.1.3 Side Loads

The hoist/winch shall be subjected to cable side loads within the envelope of the system detail specification. The side loads, up to rated load, shall be applied during hoist/winch operation throughout the speed range capability of the system if variable. Winches shall operate through full cable travel to the fully-reeled-in condition. Hoists, starting with the deadweight displaced at the maximum specification angle, shall lift the weight sufficiently clear of the ground to allow the weight to oscillate through five cycles. The hoist shall then be operated to reel out cable to return the weight to the ground.

#### 3.1.3.1.4 Loaded Cable Release

All systems which have the ability to remotely release the cable hook load shall demonstrate the functional capability under loads up to rated load and at cable lengths near the extreme reeled-in and -out positions. The cable drum shall be stationary at release. The cable wraps on the drum shall be inspected for looseness following the release, and the system then operated at no load through a complete cycle. Winch cable may be repositioned to its normal operating position prior to further operation if displaced due to backlash during release.

#### 3.1.3.1.5 Alternate Drive Operation

Any alternate or secondary hoist/winch drive systems, such as ground operation or failure back-up system, shall be demonstrated, as applicable, in accordance with the requirements of the system detail specification and with Sections 3.1.3.1.1 through 3.1.3.1.4.

#### 3.1.3.1.6 Malfunction Safety Functions

All features incorporated as malfunction detection and/or reaction devices, such as overspeed, overload, or system deterioration (i.e., chip detector, hook inoperable) shall be demonstrated at cable speeds and loads within the design limitations.

Emergency release systems shall be demonstrated functionally at the beginning and at the conclusion of the system endurance/environmental test after having been subjected to the cumulative environmental conditions of Section 3.1.1.2 in addition to the tests of Section 2.6.

#### 3.1.3.1.7 Environmental

##### A. Sunshine

A hoist/winch test article shall be subjected to the sunshine test in accordance with Section 1.1.2.3. If the hoist/winch is normally mounted in the aircraft such that the airframe normally shades the component from direct sunshine (such as internally-mounted winches or belly-mounted cargo hoists), then the Section 1.1.2.3 test is sufficient. If the hoist/winch is externally mounted and exposed to constant or frequent sunshine, especially when operating, then the sunshine test shall be conducted concurrently with and for the duration of the randomized high-temperature phase, Section 1.1.2.9A of the endurance/environmental test of Section 3.1.3.2.

#### 3.1.3.2 Endurance/Environmental Tests

The objective of the combined endurance/environmental system tests shall be to demonstrate satisfactory system functional capability, within the detail specification operating envelope, upon completion of the endurance test schedule. The test schedule shall be established in accordance with the detail specification life and mission derived from predicted loads and percentage of occurrences. The environmental conditions to which the system is exposed during endurance testing are specified in Section 3.1.1 and applied in accordance with Section 1.2.1.

The test article, as defined in Section 3.1.2, shall be subjected to the life test schedule with load levels and environmental conditions randomized according to Section 1.2.2, Experimental Test Design. The optional approach of applying a single accelerated load in accordance with Section 1.2.2.4, with environmental conditions and side loads randomized, is an allowable alternate procedure. The duration of the test is adjusted accordingly to be the equivalent of the design life.

The test article shall complete the test schedule, the duration of which shall be equivalent to the hoist/winich assembly design life, without a major structural component failure. If a major component (all of which shall be defined in the detail specification but should be considered to include cable drum, support attachment fittings, cable isolator(s), brake, and transmission) should fail in less than the equivalent design life, the component shall be replaced and the test continued until that component has achieved the design life equivalent time. All other test article components shall be considered to have successfully completed the test schedule upon their achieving the design life time. Required maintenance or replacement of these other components in order to continue testing shall not constitute a penalty but should be recorded for establishing MTBF. In addition, components other than defined major structural components shall demonstrate MTBF equal to or greater than the target MTBF specified in the detail specification.

Design changes in the test article may be incorporated during the test schedule. The life and MTBF requirements specified above shall then be demonstrated on the same test article; or at the option of the contractor, a second test article incorporating all design changes may be installed in the test chamber of Figure 13, page 171, and described in Section 3.1.5, and the test schedule, starting at zero time on the second test article, repeated. All other system component times shall be cumulative.

#### 3.1.4 Accept/Reject Criteria

The following criteria are established as the performance parameters to be demonstrated for acceptable completion of the system test program. Upon completion of the functional and environmental/endurance test programs, the hoist/winich system shall demonstrate satisfactory performance. Satisfactory performance is defined as the ability to complete 10 unloaded and 10 rated load cycles, while operating within specification cable speed requirements with no more than 5 minutes between cycles, without system malfunction. System malfunction shall be any component or interaction

of components producing system characteristics exceeding normal operating limits previously defined by specification or established during functional testing. The hoist/winch shall have demonstrated fulfillment of the specification life requirement and MTBF in accordance with Section 1.2.2.3.

### 3.1.5 Description of Facilities

The test facility design for hoist or winch system tests shall provide for a complete and comprehensive test program with a minimum of constraints. A hoist facility similar to that shown in Figure 12, page 169, or a winch facility similar to that shown in Figure 17, page 177, is recommended.

The test facility shall provide the capability for evaluating all operational effects in compliance with the design requirements of the detail specification, including:

- Hoist vertical (or deflected cable, due to load swinging) load applications.
- Winch horizontal (or deflected cable, due to remote pulley/snatch block restraint) load applications.
- Sufficient cable travel to achieve steady-state operation, and equal to at least 60% of the cable length.
- Means to apply loads up to rated loads.
- Loading to apply mass-acceleration conditions within specification operating envelope.

#### 3.1.5.1 Orientation of System Components

In order to obtain representative data on hoist/winch system operation and response, the various components must be arranged so that their relative positions duplicate those in the aircraft system as nearly as practicable. The hoist/winch facility shall provide for mounting the test article in its normal operating position with the motive drive and isolation device(s) installed.

All drive system components shall be located with representative hydraulic/pneumatic and/or electrical line lengths taking into consideration vertical head in hydraulic systems. Pumps, motors, generators, and all powered components shall be operated at design speeds. Only the test article shall be enclosed by the test chamber.

#### 3.1.5.2 Mass-Acceleration Effects

The hoist/winch system facility shall be capable of subjecting the test specimen to loads which reflect the mass-acceleration factors imposed by deadweight and dynamic loads. These conditions include starting, stopping, directional reversal, load swinging, winching obstructed travel resistance, and motive drive motoring required to restrain rated loads during transition and steady-state cable paying out. This is especially important for large, high-load-capacity cargo hoists, but also applies to winches.

#### 3.1.5.3 Hoist/Winch Cable Travel

The facility shall provide, in addition to vertical hoist and horizontal winch straight loaded cable motion, the ability to impose upon the specimen representative out-of-plane cable deflections during dynamic loading. In order to evaluate bell-mouth and cable guide, pulley, and cable wear, in addition to the associated effects of heating brake wear, and limit switch operation, controlled cable motion and accompanying friction forces must be within the capability of the facility design.

#### 3.1.5.4 Environmental Chamber

The environmental conditions specified in Section 3.1.1, Schedule of Tests, shall be applied to the test article portion of the hoist/winch system during the endurance test of Section 3.1.3.2. Figure 12 depicts a typical hoist system test article environmental chamber. Figure 17 illustrates a typical winch system test facility. The criterion for an acceptable chamber is the ability to apply and sustain the applicable portions of Section 1.2.1 required by Section 3.1.1.

### 3.1.6 Detail Specification Requirements

The detail specification for the hoist/winch system shall include the following provisions:

- A. Definition of the hoist/winch system including major components and operational parameters (i.e., voltage, amperage, pressure, flow, etc.).
- B. Definition of functional requirements and operational cycle (including cable speed range, temperature limits, measurement and indicating systems, etc.).
- C. Specification of the design life and life spectrum loading requirements.
- D. Specification of the system MTBF requirements and confidence level on its verification.
- E. Specification of extreme cable angles, cable length, load, and allowable reaction during displaced or side loading conditions.
- F. Maximum load application rate during acceleration and deceleration.
- G. Statement of established environmental resistance characteristics of materials used in the hoist construction.
- H. Specification of fluid resistance requirements.

## 3.2 POSITIONING HOIST SYSTEMS

### 3.2.1 Schedule of Tests

#### Pre-Endurance Tests

- Functional Tests
- Emergency Release System Tests
- Proof Load Tests
- Vibration Tests
- Fungus Resistance Test
- Sunshine Test
- Altitude Test
- Fluid Damage Resistance Tests
- Functional Tests

### Endurance/Environmental Tests

- Endurance Cycling
- Sand and Dust
- Salt Spray
- Extreme Temperature
- Temperature Shock
- Humidity
- Ice Accumulation
- Fluid Damage Resistance
- Rain
- Emergency Release System

### 3.2.2 Philosophy of Tests

A positioning hoist is a hoist which directly supports materiel in flight, but can position its cargo hook only when unloaded. It is used as an adjustable height "hard point", although the system typically also incorporates short-stroke lifting cylinders which are intended to lift the load off the ground once all the slack has been removed by the positioning hoist. Positioning hoists are often used in multiple-point systems. The cable drum may be powered hydraulically, electrically, or mechanically, or it may be manually adjusted. The device known as a cargo lashing reel falls into this last category. It is recognized that the range of complexity in positioning hoists is large - from the simple cargo lashing reel to a hoist nearly as complex as the largest lifting hoists now in use. For that reason, the test guidelines presented in this section are of the most general nature but, with one exception, are similar to the lifting hoist test requirements. The one exception is that the test fixture must apply the test loads, rather than being "self-applied" as with lifting hoists.

The test program recommended here for positioning hoists is a compromise from an "ideal" approach, which would be prohibitively expensive and time-consuming. The ideal approach would be to apply rigorously the provisions of Section 1.2.2.3, Reliability Test Methods, for both the "Wearout" and "Chance Failure" criteria.

Although the chance failure, or "Mean-Time-Between-Failures", requirement or the detail specification can usually be demonstrated in a reasonable test program, any reasonable wearout requirement usually means a very long test program. A more practical approach is to require that all primary components and parts of the positioning hoist system be free from major nonrepairable structural or wearout failure for a period of time equal to the system design life. This requirement can be met with one sample if there are no serious development problems. If a part fails and a redesign is undertaken, the redesigned part must be tested for one design life. Depending on the time of failure and the testing cost, the testing of the first test article, incorporating the design change, may be extended beyond the design life, or a second test article may be started at zero time on all parts. The MTBF test requirement can generally be met within the test durations required for this wearout program.

Although the recommended test program does not meet rigorous reliability criteria for wearout, it is considered adequate for the following reasons:

- The endurance/environmental test program is inherently conservative, representing all extremes of operation. Few hoists would be expected to see this in service.
- Parts of the system will be subjected to a test duration longer than design life, due to the development nature of prototype testing.
- Production runs of hoists are usually small, and a rigorous test program would often require more samples than would fail in service.

No tests are recommended for the positioning hoist itself on the component level, unless unproven state-of-the-art design concepts are used and component level development tests are indicated. These component-level tests must be designed on an individual basis, due to the wide variety of possible requirements. A component-level drive system test, for example, might involve only the drive motor, gearbox, and cable drum; or a mounting strut might be subjected to an accelerated fatigue test.

Component tests are required, however, on all other devices which are a part of the complete positioning hoist system - cable, cargo hook, emergency release devices, "lifting" devices, load isolators, power systems, instruments, controls, and displays.

As outlined in Section 2.4, load isolators often require extensive dynamic testing, which is usually not feasible, or necessary, on the system level. Load isolators, then, receive a comprehensive dynamic response and endurance test on the component level, based on the analytically predicted dynamic characteristics of the aircraft and load system. On the system level, the load isolators are again subjected to endurance testing, but of a different nature, since step input "lifting" cycles differ from the steady-state dynamic inputs of airframe vibration. Finally, when a flight test vehicle is available, the predicted dynamic characteristics of the positioning hoist system are compared to the actual characteristics.

It is recommended that all the tests listed in Schedule of Tests be conducted on each test article, in the order indicated, according to the provisions of the next section, Methods and Procedures. Those tests which are thought not to have an interaction with simultaneous endurance operation of the test article are done prior to endurance testing. Of course, any deleterious effects of these environments may be exaggerated by the endurance cycles. One test which may or may not interact with endurance testing is fluid damage resistance. In this case, the test is conducted prior to endurance testing, and if adverse effects are noted, or if the hoist environment is likely to include frequent exposure

to one or more fluids, these fluids are applied periodically in the endurance test as well. Hydraulically powered hoists, for example, should be periodically sprayed with hydraulic oil so that any interactions with environments such as sand and dust may take place.

### 3.2.3 Methods and Procedures

Each test article shall be subjected to the following test program, the test article being defined as the positioning hoist assembly itself and all closely associated components such as isolators, lifting cylinders, and mounting struts. All other components of the complete positioning hoist system shall be installed at the test facility for support of the test article(s), but need not be mounted within the test chamber. These components shall include, as applicable, power systems, controls, instruments, and displays.

The number of test articles shall be sufficient to meet both of the following requirements:

- (1) Demonstrate the mean-time-between-failures requirement of the detail specification according to the provisions of Section 1.2.2.3, Reliability Test Methods.
- (2) Demonstrate freedom from major nonrepairable structural or wearout failure of all primary components, as defined in the detail specification, for a period of operation equal to the design life. The tests on the system shall be extended, or another test article put in the test program, when any primary component is changed, in order to operate every component of the final system design for a period equal to the design life.

#### 3.2.3.1 Functional Tests

All functional features of the positioning hoist design shall be demonstrated, with two exceptions. When the emergency release system is destructive, such as an explosive cable cutter, tests are performed according to the following section. Also, load isolators need not receive a complete dynamic response test, since this is accomplished at the component level. If possible, however, a simple transient response test is to be done in order to monitor load isolator performance.

A typical positioning hoist functional test cycle (used on cargo lashing reels) is as follows:

- unlock reel
- pull cable to specified length
- lock reel
- apply rated static load at hook
- retract lifting cylinder and time cycle
- extend lifting cylinder and time cycle
- quickly release load and time isolator return
- unlock reel
- rewind cable
- lock reel

#### 3.2.3.2 Emergency Release System Tests

When the means for emergency load release is nondestructive, the system shall be functionally tested concurrently with the other functional features. When this system is destructive, as with explosive cable cutters, a functional check is required only at the beginning of the test program and at the end of the environmental/endurance test. Dummy cables may be used for these tests.

The test shall be conducted with a static cable load equal to 5% of rated static load. The emergency release system, including any redundant features, shall be actuated by the same means used in the aircraft installation. The system is acceptable only if all release devices function as designed.

#### 3.2.3.3 Proof Load Tests

The complete positioning hoist system shall be subjected to a static proof load equal to the limit load for a period of 5 minutes at each extreme cable angle. Any evidence of slippage, rupture, or permanent detrimental deformation, unless some deformation is specifically allowed in the detail specification for nonmetallic components, shall be cause for rejection.

#### 3.2.3.4 Pre-Endurance Tests

The remainder of the pre-endurance tests shall be conducted on each test article according to the applicable Sections of 1.1, Environmental Test Methods: 1.1.2.1 Vibration, 1.1.2.2 Fungus, 1.1.2.3 Sunshine, 1.1.2.4 Altitude, and 1.1.2.5 Fluid Damage Resistance. In addition, functional tests according to 3.2.3.1 shall be performed as required to monitor the effects of environments and at the conclusion of these tests.

Of these tests, sunshine, fungus, altitude, and fluid damage resistance may be deleted if the test article clearly will be unaffected by these environments, as stated in the detail specification. Sunshine and fungus testing may be performed on representative material samples of the test article, except for nonmetallic structural members, which are sunshine tested full size prior to endurance. In either case, if the test produces adverse results, the environment(s) shall be added to the endurance test.

#### 3.2.3.5 Endurance/Environmental Tests

Each test article shall be subjected to endurance cycling and each of the tests listed under endurance tests in the schedule of tests in accordance with the applicable Sections of 1.1, Environmental Test Methods: 1.1.2.7 Sand and Dust, 1.1.2.8 Salt Spray, 1.1.2.9 Extreme Temperature, 1.1.2.10 Temperature Shock, 1.1.2.11 Humidity, 1.1.2.6 Ice Accumulation, 1.1.2.5 Fluid Damage Resistance, and 1.1.2.12 Rain. The endurance cycle, the duration of the test, and the test conditions shall be determined by the requirements of the detail specification and Section 1.2, Experimental Test Design. The environments shall be applied according to

Section 1.1, Environmental Test Methods. The test facility shall be capable of the same basic functions as that shown in Figure 17, page 177. Loading shall be accomplished by a winch and loading cylinder or similar means capable of providing test loads over the desired range of hook positions.

The endurance test shall be based on typical use cycles such as the functional test of 3.2.3.1. The object of the endurance/environmental test shall be to demonstrate the MTBF requirement of the detail specification and to operate all primary components and parts of the system without major nonrepairable structural or wearout failure for a time equal to the design life. The endurance test may be accelerated using the procedures of Section 1.2.2.4, Test Acceleration Methods, provided the acceleration factor in time does not exceed 2.0.

Those aspects of functional tests not specifically covered in the endurance test cycle shall be periodically checked in order to monitor system performance. At the completion of all other tests, the emergency release system shall be functionally checked in accordance with 3.2.3.2.

#### 3.2.4 Accept/Reject Criteria

As outlined in Section 1.2.2.3, Reliability Test Methods, there are two basic types of test failures to consider: wearout and "chance" failures. The wearout criterion is to be applied to nonrepairable major structural or primary wearout failures. The "chance" failure criterion is to be applied to the less important repairable failures usually considered in determining an MTBF for the test article. The MTBF criterion shall be used as required in Section 1.2.2.3 and shall meet the requirements of the detail specification. However, since the verification of a realistic wearout reliability on a complex device such as a hoist is prohibitively expensive, the only wearout criterion used is that all primary components and parts operate without nonrepairable major structural or wearout failure for a time equal to the design life.

Further causes for rejection are: damage or detrimental deformation in the proof load test, failure to meet functional test requirements at any time in the test program, and failure of any component of the emergency release system during the test program. Note that the reliability requirements for emergency release systems are generally much higher than that for the hoist itself, due to the safety-of-flight consideration. It is generally much more practical to verify this reliability requirement on the component level where many samples can be tested, as outlined in Section 2.6, Emergency Release Devices. The inclusion of these devices in the system test is an opportunity to further check this reliability in a good simulation of service use, and any failure in this small sample would easily lower the estimate of the system's reliability below the detail specifications requirements.

### 3.2.5 Description of Facilities

#### A. Proof Load Facility

This facility shall be capable of applying the required limit load at each of the extreme cable angles specified. The load is to be applied at the cargo hook and reacted at the positioning hoist system mounting hard points.

#### B. Pre-Endurance Test Facilities

Test chambers and facilities shall be used as required in the applicable parts of Section 1.1, Environmental Test Methods. Altitude, sunshine, and fungus test chambers are commercially available, as are vibration test tables of sufficient size to handle the test article.

#### C. Endurance/Environmental Test Facility

The endurance/environmental test facility shall be able to perform the same basic functions as the facility shown in Figure 17, page 177. This, in turn, is similar to the construction of the facility for lifting hoists, Figure 12, page 169. The facility shall be provided with, in addition to the dust circulation system, a salt fog system, a rain system, if required, and an environmental control system

capable of providing the extreme temperature, humidity, and temperature shock atmosphere required. This can be accomplished with commercially available "portable" environmental units.

The winch/cylinder loading system shown in Figure 17, page 177, or equivalent, shall provide the capability of applying test loads and cable positions as required in the randomized test plan. This can be as simple as a manually controlled hydraulic system for simple programs, or as complex as a completely automated cycling and loading system for major programs.

If required, provisions shall be made for changing the orientation of the hoist relative to the loaded cable so that operation at various cable angles may be simulated.

#### 3.2.6 Detail Specification Requirements

The detail specification for the positioning hoist shall include the following provisions:

- A. Definition of the hoist system and primary structural components
- B. Definition of functional requirements and operational cycle
- C. Specification of the design life and life spectrum loading requirements
- D. Specification of the system MTBF requirement and confidence level on its verification
- E. Specification of limit load, extreme cable angles, and allowable proof load deformation
- F. Specification of fluid resistance requirements
- G. Specification of vibration test levels and test duration
- H. Statement of established environmental resistance characteristics of materials used in the hoist construction

### 3.3 MULTIPLE-POINT HOISTING SYSTEMS

#### 3.3.1 Schedule of Tests

- (1) Operational Compatibility
- (2) Emergency Release System

#### 3.3.2 Philosophy of Tests

Multiple-point hoisting systems usually contain two, three, or four hoisting devices. A typical system would be a four-point cargo hoist system. A four-point positioning hoist system utilizing lifting cylinders would also fall into this classification, since this system, though stroke limited, can hoist a load at multiple points.

The purpose of these tests is to determine that the multiple hoisting devices, previously qualified as components or "subsystems", function properly as a system without improper interaction. Additionally, performance of emergency release systems, also previously qualified, must be demonstrated at this combined system level. No additional endurance or environmental tests are required.

Since these are system tests, all system features should be included in the test setup. This would include such features as:

- The aircraft multiple hoisting system control
- Cable loading indicating system
- Cable length indicating system
- The hoisting device power system
- Hook status indicating system
- Hook release system
- Load isolating system

### 3.3.3 Methods and Procedures

#### 3.3.3.1 Operational Compatibility

- (1) The hoisting system shall be set up in a suitable test facility such as shown in Figure 12, page 169. The test setup shall include:
  - The hoisting devices
  - The power system
  - The control system
  - The emergency release system
  - The indicating system
  - A test loading system
  - A test measurement system
- (2) The system shall be operated and tests shall demonstrate:
  - Lifting capability through specified load c.g. range
  - Hoisting device synchronization under all load and load c.g. extremes
  - Normal load release capability
  - Full up - down limited protection
  - Hoisting - lowering speed control
  - Accuracy of any length, load, or other indicating system
  - Specified overall system efficiency
  - Single-point or submultiple hoisting capability
  - Ability to correct the attitude of a skewed load

#### 3.3.3.2 Emergency Release System

A demonstration test of the multiple-point hoisting system's emergency release system shall be performed at the completion of all other tests. If it can be substantiated analytically that one loading condition is the most severe test of the emergency release system, then the system need only be demonstrated at this load. If the most severe loading condition cannot be predetermined, tests shall be performed at maximum and low-load (approximately two percent of maximum) conditions. The goal of the test shall be to demonstrate that release is simultaneous and complete. It should be noted that partial or nonsimultaneous release of a load can be more detrimental to the aircraft than no release.

#### 3.3.4 Accept/Reject Criteria

The system design shall be considered rejectable for any of the following reasons:

- Failure to meet load and/or speed requirements
- Failure to synchronize hoisting speed or distance within specified acceptance tolerance
- Failure of indicating systems to indicate properly
- Failure of measurement systems to measure within specified limits
- Failure of release system to release or release with specified simultaneity

#### 3.3.5 Description of Facilities

##### (1) Hoisting Facility

The multiple point hoisting system shall be installed in a suitable facility, such as the Hoist System Test Facility shown in Figure 13, page 169. Hoisting devices shall be located to duplicate the system geometry as installed in the aircraft. The facility shall provide basic power to drive the hoisting device power system.

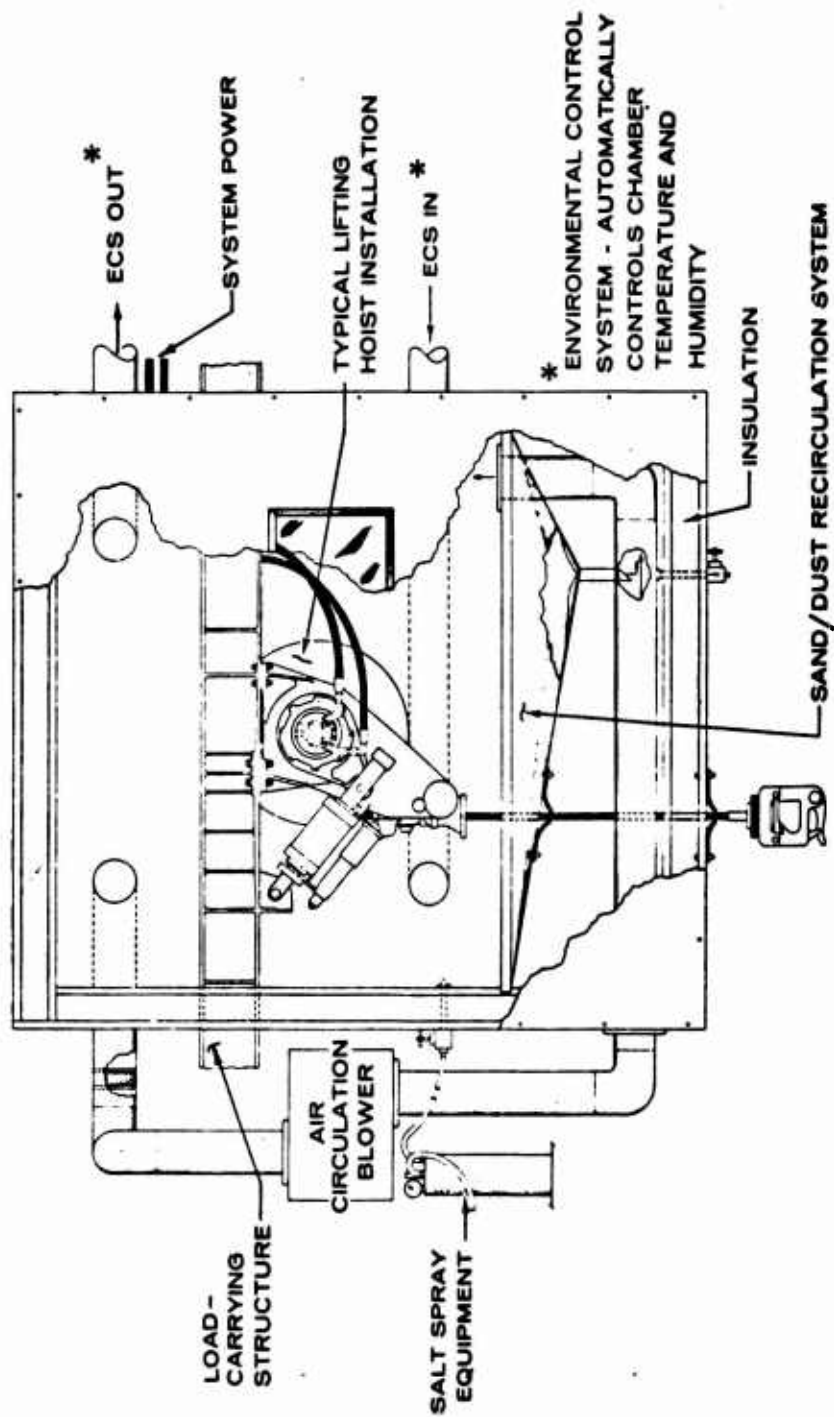


Figure 12. Hoist System Endurance/Environmental Chamber.

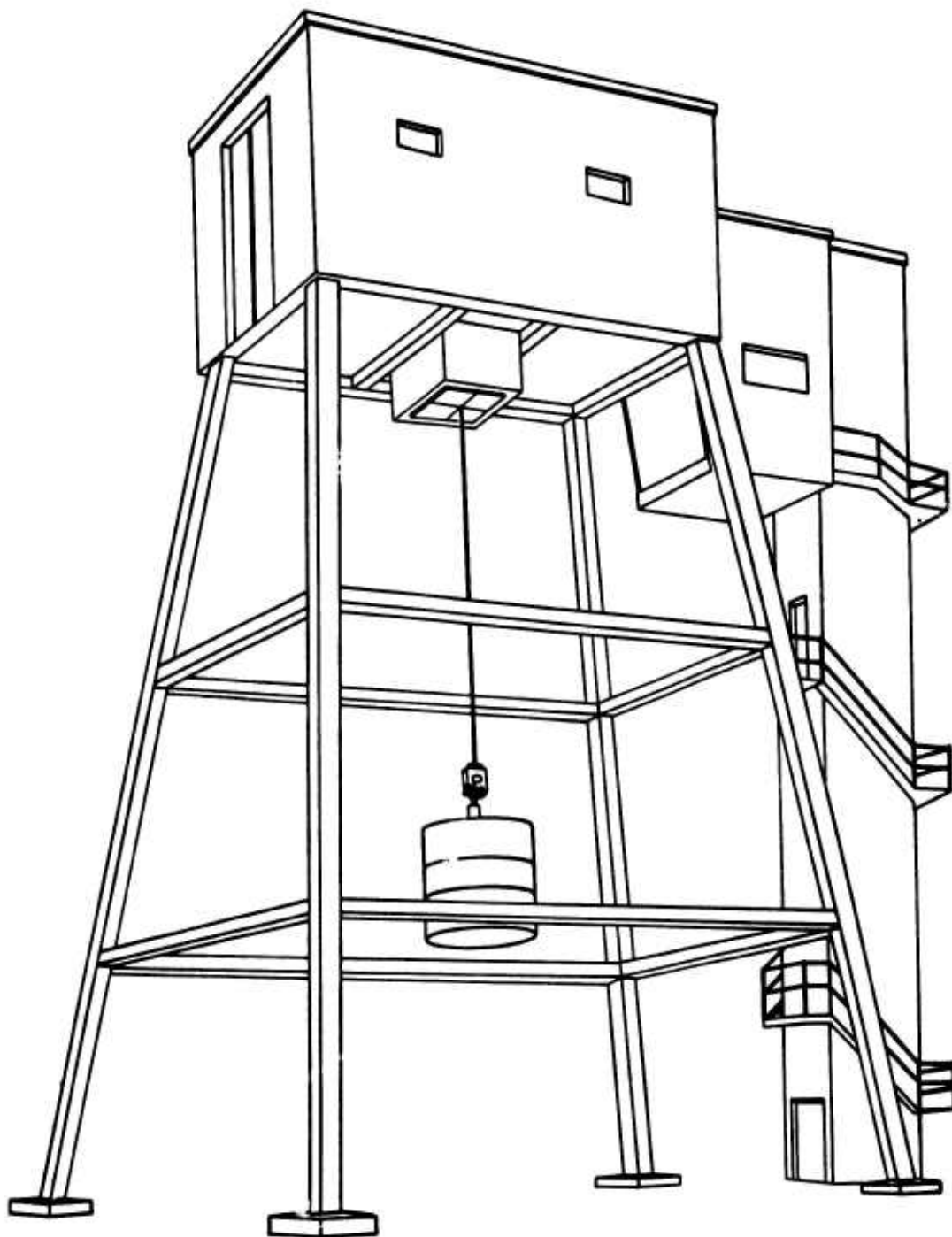
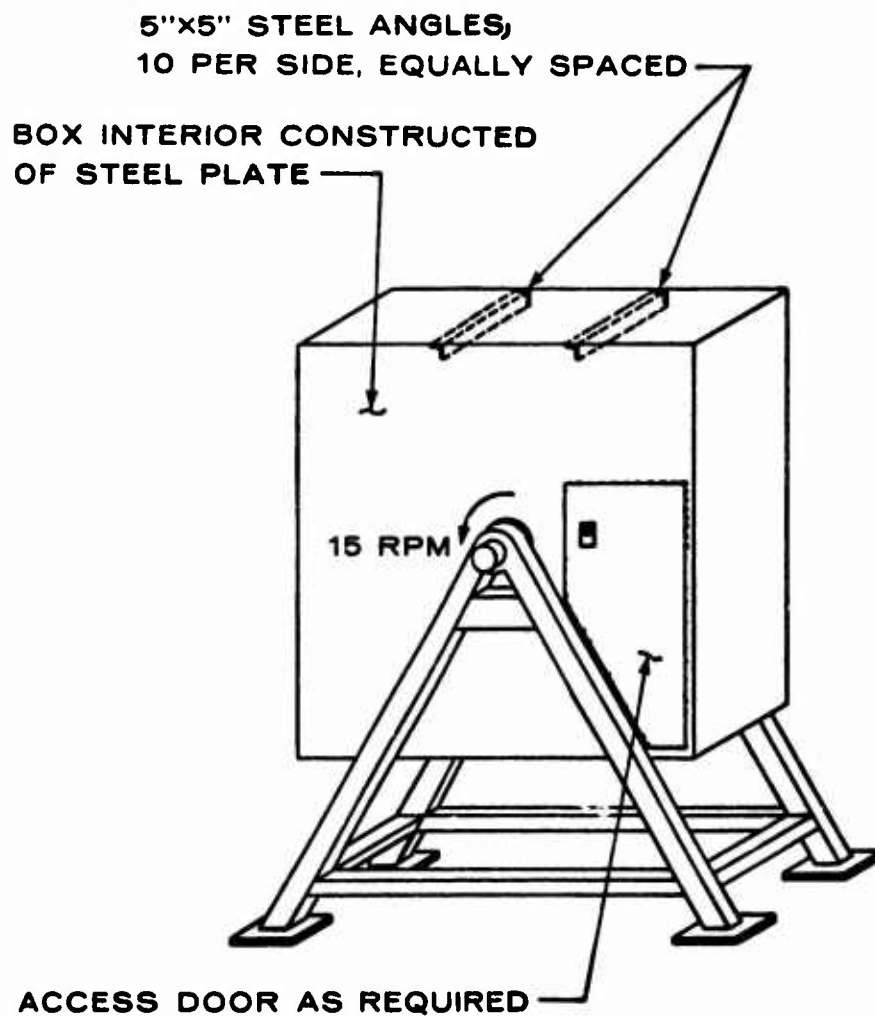
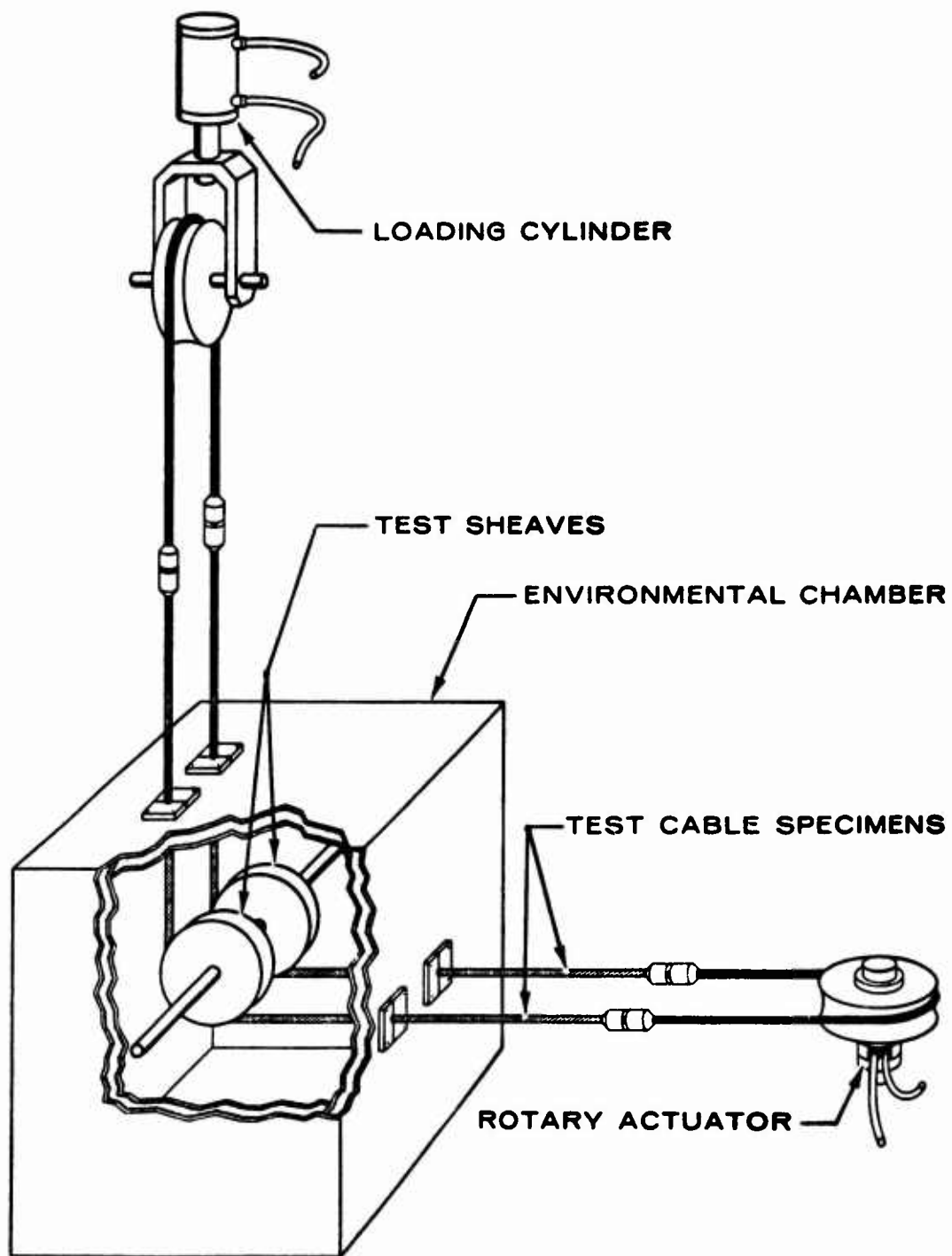


Figure 13. Hoist System Test Facility.



**Figure 14. Rough Handling Test Box.**



**Figure 15. Cable/Sheave Test Facility.**

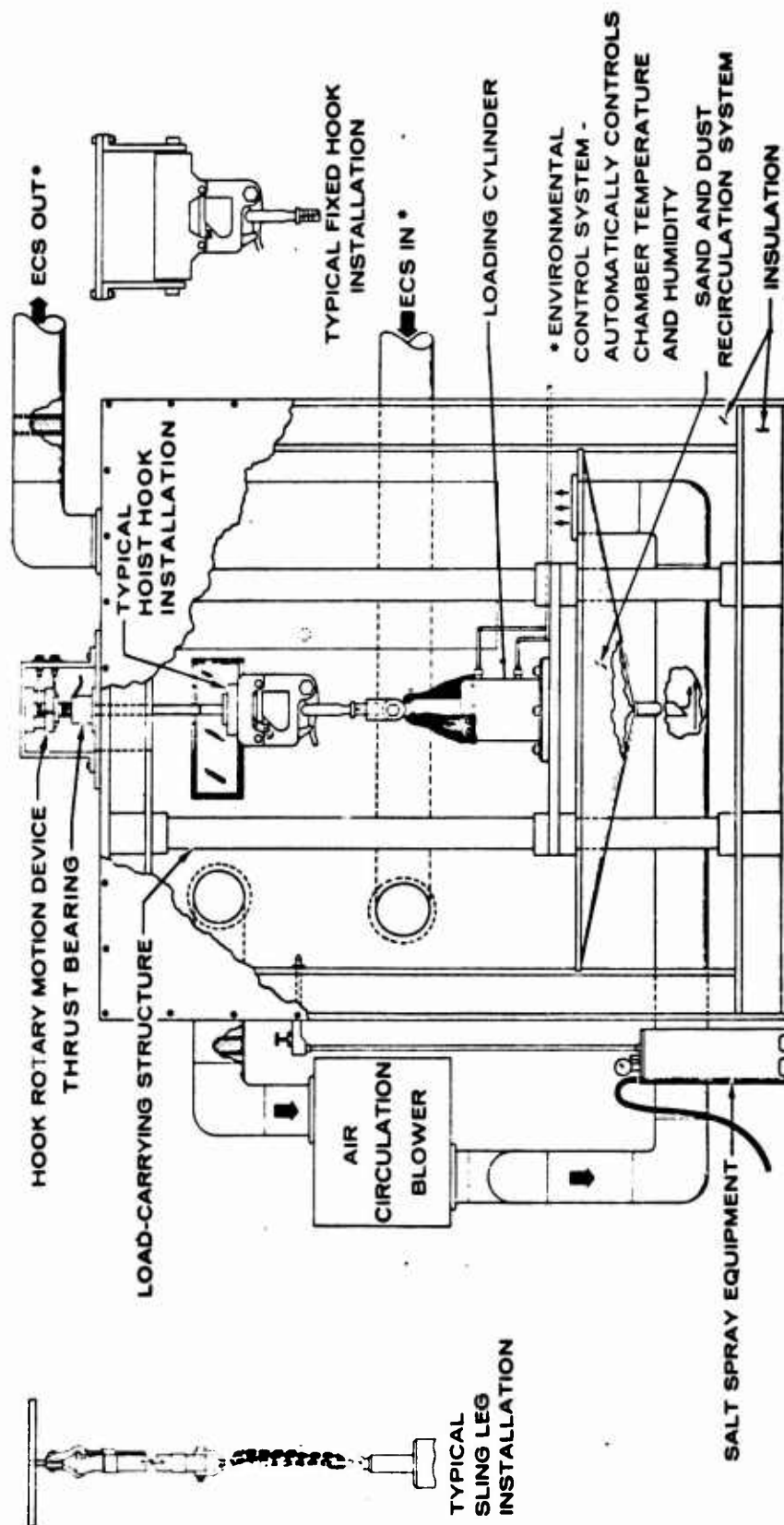


Figure 16. General Endurance/Environmental Chamber.

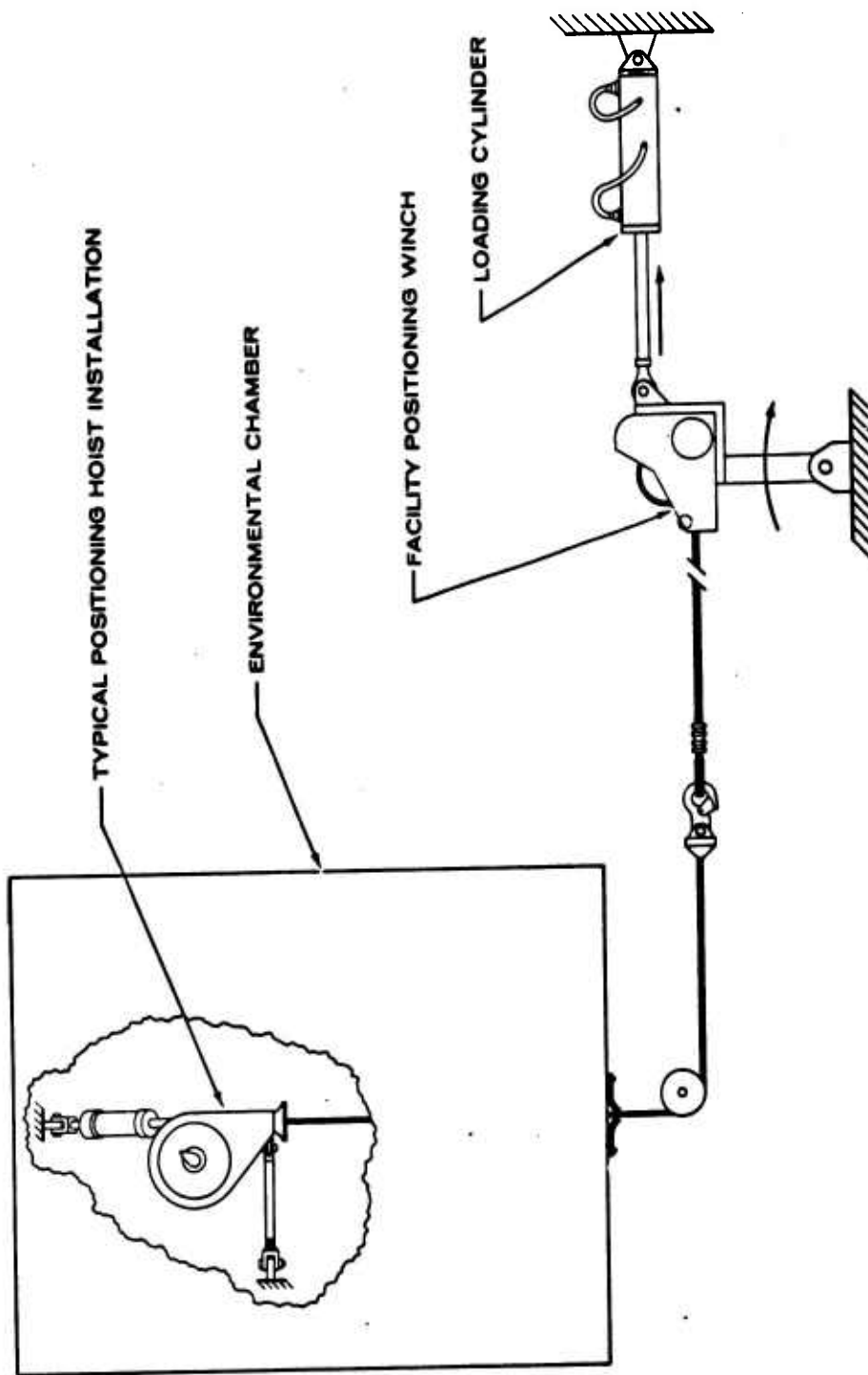
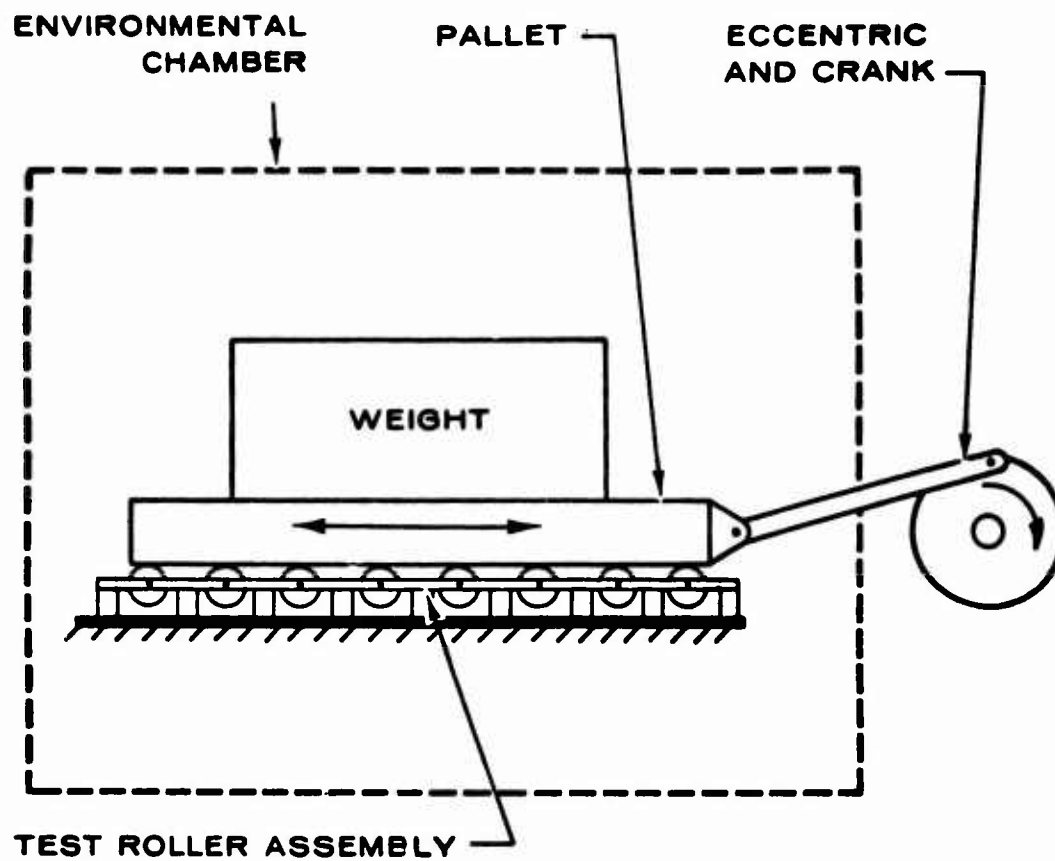


Figure 17. Winch/Positioning Hoist Test Facility.



**Figure 18. Roller Endurance/Environmental Test Facility.**

## **(2) Test Loading System**

The test loading system shall provide test loads of magnitude and center-of-gravity location as required by the system operational envelope. A pallet is suggested for this system, with pickup points to match the number of hoisting devices and variable dead-weight load capable of being relocated on the pallet to provide center-of-gravity trim. The deadweight should also be capable of being used for single winch loads.

### **3.3.6 Detail Specification Requirements**

The detail specification for multiple-point hoisting systems shall include the following provisions:

- (1) Specification of hoisting requirements, including all point and submultiple load capabilities and speed requirements**
- (2) Specification of synchronization accuracy**
- (3) Specification of system measurement capabilities**
- (4) Specification of system load release requirements for normal and emergency conditions**
- (5) Specification of system indicating capabilities**

#### 4. QUALITY ASSURANCE PROVISIONS

The following provisions shall be made when performing cargo handling systems qualification tests:

##### 4.1 Selection of Test Articles

The test article shall be representative of the population of components of the design being qualified. When possible, parts for assembly of the test article(s) shall be randomly selected from a batch of production parts. Buildup procedures shall not differ from production procedures.

##### 4.2 Conformity Inspection

All test articles shall be subjected to independent inspection for conformity to applicable drawings and buildup procedures.

##### 4.3 Identification of Components

All functional assemblies shall be identified with a buildup record and use log. These logs shall be periodically updated to reflect pertinent history, installation date, removal date, reason for removal, and total operational cycles.

##### 4.4 Instrumentation

The accuracy of instruments and test equipment used to control or monitor test parameters shall be periodically verified according to the requirements of MIL-C-45662A, "Calibration System Requirements."

##### 4.5 Test Log

A chronological record of the test program shall be maintained, and will include operational cycles, failures, maintenance, inspections, system changes, and test data.

## CONCLUSIONS

1. The use of the requirements and test methods specified in this report will result in more reliable cargo handling systems.
2. Detail specifications prepared for cargo handling systems to be tested according to these requirements must include the specific reliability requirements, and definitions of use conditions and environments required to design a realistic test program.
3. The increased cost of these test programs will be compensated for in the form of increased reliability, decreased maintenance, fewer redesign/retrofit programs, and assured materiel delivery.

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## GLOSSARY

The following definitions apply for the terms used in this report.

Breaking Strength - The load at which a component fractures or parts. This is a property of the component under test, as opposed to the design requirement - ultimate load requirement. The terms "ultimate strength" and "ultimate load" are avoided in this report as having two possible interpretations.

Cable - The flexible tension member that connects a hoist or winch with a cargo hook. The word "cable" to mean "wire rope" is not used in this report. A cable may be metallic or nonmetallic.

Cargo Handling System, Helicopter - An aircraft-mounted system which changes the location of, or restrains and controls, the helicopter payload.

Cargo Hook - The mechanical device, connected to a cable or fixed to the aircraft, which acquires the load. "Releasable" hooks may be "opened," allowing the load attachment point to drop away. Many releasable hooks may be opened under load. "Fixed" hooks are fixed to the aircraft, sometimes through a swivel. Fixed hooks may be releasable or nonreleasable.

Cargo Restraint - A device to restrain cargo from moving within the helicopter or container. Devices such as cargo tie-down straps, cargo restraining nets, and their associated hardware - hooks, length adjustment features, and pre-tensioning devices - are included in this category.

Container - An article of transport equipment: designed to facilitate the movement of goods by one or more modes of transportation without intermediate reloading; of permanent design strong enough for reuse; and fitted with devices permitting ready handling and transfer from one mode of transportation to another.

Design Life - The length of time, in aircraft hours or component operating hours, that a device is to operate without major nonrepairable component failure. For many devices, the design life is better defined in terms of operating cycles.

Design Specification - The term "detail specification," as defined below, is preferred.

Detail Specification - The top specification for the component or system being tested. This specification, generally contractor prepared and customer approved, describes in detail the functional requirements, mission and life requirements, environments of operation, and general test considerations.

Emergency Release System - A system which releases or cuts away the payload when other means of release fail to function properly. These systems may be destructive or nondestructive.

Endurance Test - A test simulating service operation of the test article over many repetitive cycles, generally employing acceleration factors.

Environmental Test - A test where environmental conditions, either natural or induced, are applied to the test article to simulate service operation.

Hoist - A device which lifts a load vertically, generally by means of a cable and drum. A "positioning" hoist can support a load but can only position its cargo hook when unloaded.

Life Spectrum - A description of the spectrum of loads, motions, and environments which are expected to be applied to a component during its design life. This may be stated as a number of mission spectrums.

Limit Load - The maximum load that the component may see in service; includes static load plus maximum dynamic load due to maneuvers and other dynamic conditions.

Load Isolator - A device designed to provide spring and/or damping in a cargo handling system for the purpose of reducing adverse dynamic coupling between the load and the aircraft.

Materiel - Material equipment, apparatus, and supplies of an organization or institution. The cargo transported by the helicopter.

Mission Spectrum - A description of the spectrum of load, environments, and other independent variables which are expected to be applied to a component during a typical operational mission.

Multiple-Point Hoisting System - A system of two or more hoisting points which operate on a common control system.

Net - A specialized cargo sling which can carry different types of material otherwise not easily contained. Usually of mesh construction.

Pallet - A portable shallow container or platform for holding one or more units for storage or transport, intended to be handled mechanically as a single unit.

Pendant - A tension member, usually flexible and not adjustable in length, interconnecting an aircraft attachment point and a load attachment point such as the apex of a sling or cargo net.

Pod - A specialized container designed for a specific cargo or mission and generally having a unique shape or configuration best suited for that cargo or mission.

Power System - The system which provides the motive power for the cargo handling system. It may be hydraulic, pneumatic, electrical or mechanical. It includes the appropriate pumps, valves, lines, generators, switches, wires, drives, and controls. The system motive power device - the hydraulic, electric, or pneumatic motor, or the mechanical drive - may also be defined as a part of the power system, depending on the individual system configuration.

Proof Load - The static load, usually considered nondamaging, applied to the test article to demonstrate structural integrity.

Qualification Test - The series of tests designed to substantiate a new component or system design for its intended use. These tests are performed on only a small sample of the total production run of devices.

Randomization - The application of the various levels of each independent variable in a random order.

Rated Static Load - The static weight that may be carried by a cargo handling system. Does not include dynamic effects.

Reliability - The probability of a device or system performing its purpose adequately for the period of time intended under the operating conditions encountered.

Rigging Points - Eyes, yokes, rings, or fittings permanently fixed to the aircraft, or cargo-carrying pod, for the purpose of securing a load. Aircraft "hard points."

Rollers - Small wheels or cylinders over which the materiel is rolled into or out of the aircraft.

Sheave - Small wheel with grooved rims used with hoisting or winching systems to change the direction and application of the applied cable force, and when combined in blocks to amplify the applied force. A pulley.

Sling - A tension member which can connect material of almost any shape to a helicopter carrying point. The sling may be multiple or single leg, metallic or nonmetallic. An apex fitting is used to connect the sling legs together and to serve as the top attachment point.

Test Acceleration - A means of shortening the duration of a test program by increasing the load or environments above normal levels. Each test hour, or cycle, is then equivalent to more than one "flight" hour, or cycle.

Test Article - The individual device or component being subjected to the test.

Test Cycle - A series of events which simulates operation of the test article in service.

Ultimate Load Requirement - The load, possibly damaging, which the test article must withstand without fracture. A design requirement.

Winch - A device which draws a load horizontally by means of a cable and drum, and may also restrain a load in position.

APPENDIX I  
LOG-NORMAL DISTRIBUTION

The use of the "normal" or Gaussian distribution to analyze test data is often inadequate when the phenomena being investigated cannot go to both high and low extremes in value. An example of this is fatigue, or life, data where the probability of an extreme "high" result is much greater than an extreme "low" result, and a negative life is impossible.

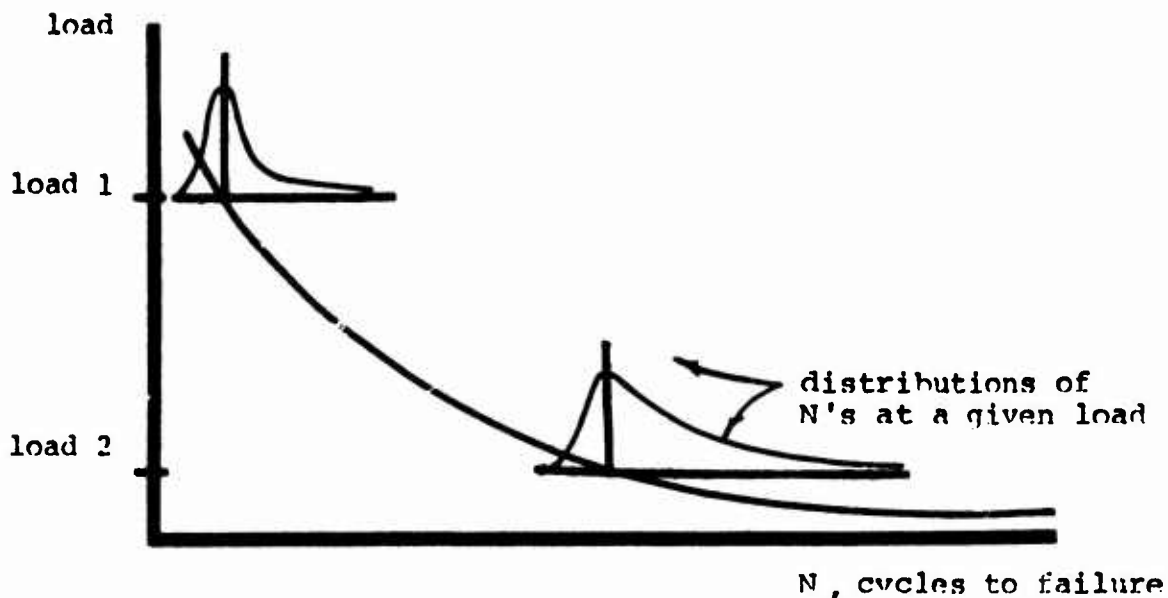


Figure 19. Typical S-N Curve.

The distribution of N at any given load is seen to be skewed to the positive direction in the typical S-N curve shown above. The degree of skewing increases greatly for large N, and this development is valid only for low-cycle life data.

If the logarithm of each data value is taken (usually base 10) and is plotted on a linear scale, or if the data value itself is plotted on a logarithmic scale, a "normal" distribution results:

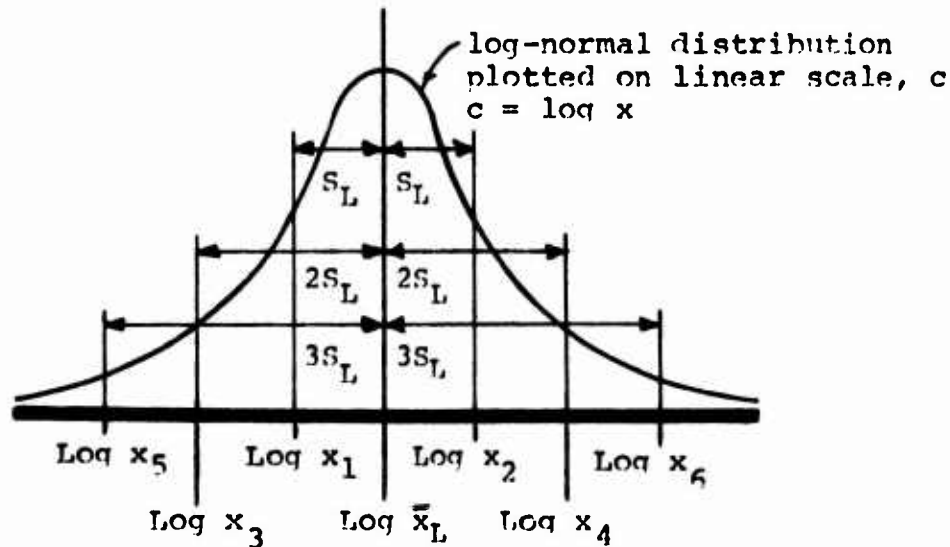


Figure 20. Log-Normal Distribution.

In the above figure,  $\log \bar{x}_L$  is the mean of the  $\log x$  data:

$$\log \bar{x}_L = \frac{\sum \log x_i}{n}$$

and  $S_L$  is the standard deviation of the  $\log x$  data:

$$S_L = \sqrt{\frac{\sum (\log \bar{x}_L - \log x_i)^2}{(n-1)}}$$

where  $\log x_i$  is the base 10 logarithm of the  $i^{\text{th}}$  data point and  $n$  is the number of data points.

If the same increments and points are plotted on a distribution of the same data in linear coordinates, the data appears as follows:

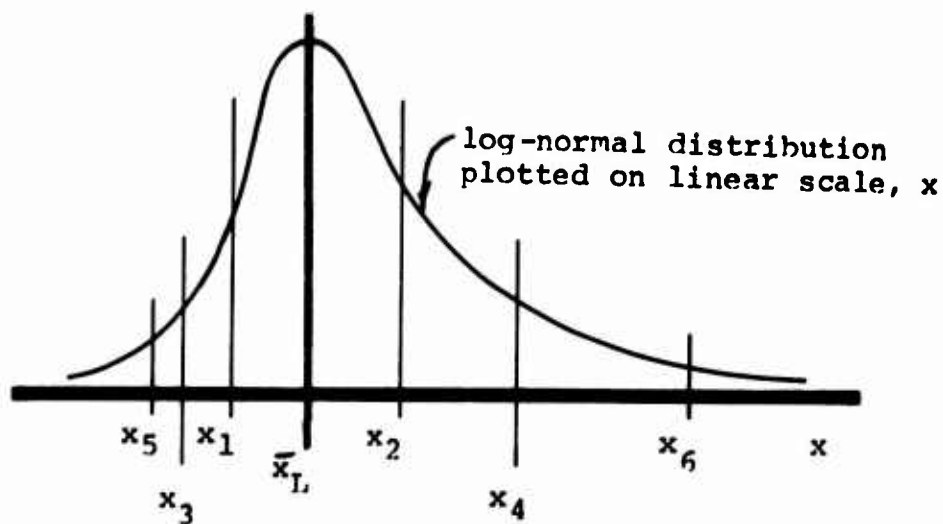


Figure 21. Log-Normal Distribution.

Note that  $\bar{x}_L$ , the peak of the distribution, does not equal  $\bar{x}$ , the mean of the distribution, due to skewness.

Although  $\bar{x}_L$ , the antilog of the mean of the log  $x$  data, has meaning in linear coordinates, the antilog of  $S_L$ , the standard deviation of the log  $x$  data is not so easily translated to the standard deviation in linear coordinates. In fact, there is no rigorous definition for the standard deviation of a skewed distribution.

All statistical operations with the log-normal distribution are accomplished on log coordinates, where all the well-known properties of the standard normal distribution can be used;  $+ 1S$  encompasses 68% of the data,  $+ 2S$  encompasses 95%, etc. The properties of the distribution can then be translated to linear coordinates using the following analysis:

Log  $x_1$  is the first lower increment of  $S_L$  from  $\log \bar{x}_L$ , or

$$\text{Log } x_1 = \text{Log } \bar{x}_L - S_L$$

Similarly,

$$\text{Log } x_2 = \text{Log } \bar{x}_L + S_L$$

$$\text{and } \text{Log } x_3 = \text{Log } \bar{x}_L - 2S_L, \text{ etc.}$$

Now define  $k$  such that

$$\text{Log } 1/k = S_L \text{ or } k = 1/(\text{Log}^{-1} S_L)$$

$$\text{Then } \text{Log } x_1 = \text{Log } \bar{x}_L - S_L = \text{Log } \bar{x}_L - \text{Log } 1/k = \text{Log } k \bar{x}_L$$

$$\text{or } x_1 = k \bar{x}_L$$

$$\text{Similarly, } x_2 = \bar{x}_L/k$$

$$\text{Log } x_3 = \text{log } \bar{x}_L - 2 \text{ Log } 1/k = \text{Log } k^2 \bar{x}_L$$

$$\text{or } x_3 = k^2 \bar{x}_L$$

$$\text{Similarly, } x_4 = \bar{x}_L/k^2, \quad x_5 = k^3 \bar{x}_L, \text{ etc.}$$

In general, a point in linear coordinates which is  $r$  standard deviations below the mean of a log-normal distribution can be described by

$$x = k^r \bar{x}_L$$

where  $r$  is any number positive for increments below the mean and negative for increments above the mean, and  $k$ , the linear deviation factor, is determined from  $S_L$ .

Often it is desired to have some linear equivalent of the log-normal distribution's standard deviation. One possible definition is the width of the first lower increment of  $S_L$  in linear coordinates, called  $S_1$ .

$$\begin{aligned}
 S_1 &= \bar{x}_L - x_1 \\
 &= \bar{x}_L - k \bar{x}_L = \bar{x}_L (1-k)
 \end{aligned}$$

$$\text{or } S_1/\bar{x}_L = 1-k$$

$$\text{Further, } k = \bar{x}_L - S_1/\bar{x}_L = 1 - S_1/\bar{x}_L$$

$$\text{and } S_L = \text{Log } \bar{x}_L/\bar{x}_L - S_1$$

As an example, consider the following data:

$x = 63, 81, 98, 102, 105, 107, \text{ and } 158$

If this were analyzed as a normal distribution,

$$\bar{x} = 102 \text{ and } S = 29$$

Taking base 10 logs to find the log-normal distribution,

$$\text{Log } x = 1.80, 1.91, 1.99, 2.01, 2.02, 2.07, \text{ and } 2.20$$

$$\text{Then } \text{Log } \bar{x}_L = 2.00 \text{ or } \bar{x}_L = 100$$

$$\text{and } S_L = 0.125$$

$$\text{Then } k = 1/\text{Log}^{-1} S_L = 1/1.34 = .75$$

$$\text{and } x_1 = k \bar{x}_L = .75 \bar{x}_L = 75, S_1 = 25$$

$$x_2 = \bar{x}_L/k = 1.34 \bar{x}_L = 134, S_2 = 34$$

The use of a normal distribution analysis when, in fact, the data is more nearly log-normal can involve considerable error, especially at the low end of the distribution. If we wished to find the value above which 97% of the data occurred (2 standard deviations),

$$\text{Log normal: } x = k^2 \bar{x}_L = .56 \bar{x}_L = 56$$

$$\text{normal: } \bar{x} - 2S = 102 - 58 = 44$$

and for 99% (2.3 standard deviations),

$$\text{Log normal: } x = k^{2.3} \bar{x}_L = .52 \bar{x}_L = 52$$

$$\text{normal: } x = \bar{x} - 2.3S = 102 - 67 = 35$$

APPENDIX II  
SIKORSKY HELICOPTER CARGO HANDLING SYSTEM  
RELIABILITY DATA

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I. CH-54A

A. Single-Point System

Failures of the cargo hook release system dominate the CH-54A problem list. This symptom generally results from moisture-contaminated slip rings in the hook swivel assembly, an electrical open or short circuit in the hoist cable, or a material buildup on the cargo hook assembly load beam latch. Changes incorporated to reduce the number of release system failures include: a new swivel assembly bumper of molded rubber lip to protect the swivel from contaminants; a slip ring with redundant electrical contacts, operable in moist environments; improved antibacklash features to prevent binding and kinking of cable assembly (a suspected cause of cable internal electrical failure); increased latch corner radius to permit unrestricted movement of the latch when the release system is activated.

In addition, Sikorsky has found that line losses in hook release circuitry frequently contribute to improper release problems. These losses amount to a voltage drop in the cable circuitry, resulting in insufficient voltage to operate the release. A program is currently under way to provide 115 volts A.C. at the hook, to rectify it, and to reduce it there to the required D. C. value, thus effectively eliminating cable resistance in the circuit.

B. Four-Point System

Load-leveler control (controlex) problems are most numerous, apparently resulting in part from a loss of adjustment due to vibration. CH-54B aircraft have been modified to eliminate the controlex configuration entirely.

## II. CH-54B

### A. Single-Point System

Decoupler housing failures accounted for eleven confirmed hoist system failures, leading all other causes. It is suspected that these failures result from fatigue, and possible modifications are being investigated.

### B. Four-Point System

Distinct trouble spots are still difficult to define. However, the benefits of several configuration changes from CH-54A to CH-54B models will be determined when sufficient flight time accumulates.

## III. CH-53A/D

### A. External Cargo Hook Installation

#### 1. External Cargo Hook

Field discrepancy reports indicate that failures of the cargo hook result from load beam latch deformation, corrosion, and contamination. Actions taken by Sikorsky to reduce the impact of these problems include:

- a) Load beam and keeper now stripped and recadmium plated at overhaul
- b) Provisions for rework of latch cam radius to drawing specifications
- c) Incorporation of thorough check-out procedures for hook solenoid and microswitches at overhaul

#### 2. External Cargo Hook Access Door Assembly and Handle

The access door (particularly the handle) is frequently damaged during cargo loading/unloading operations. There is some evidence to suggest that this damage results from improper stowage.

## **B. Cargo Winch Installation**

### **1. Cargo Winch Controllable Hydraulic Pump**

Piston seizure has been the largest contributor to 64WH080001-1 winch pump problems. Symptoms resulting from this condition include leakage, cracks in the pump housing, and incorrect pressure output. A change from steel to bronze on the internal surface of the pump cylinder has reduced pump seizures. However, the overall reliability problem with this pump has resulted in a change to another vendor. The new pump, P/N 65055, has exhibited increased reliability, though it is not without its problems either. Steps have been taken to reduce incidence of these failure modes, which include improper pump response, servo valve problems, clearances, filter problems, and motoring problems.

## **IV. CH-3C/E and HH-3E**

### **A. General**

Reliability of CH-3C/E and HH-3E cargo systems compares favorably with that of other aircraft types considered. ECP activity applicable to these cargo systems has been minimal.

### **B. Cargo Loading and Rescue Hoist Winch Installation**

The winch assembly and associated hoist control box assembly account for the vast majority of cargo system failures and represent a combined total of 581 maintenance man-hours in 104,000 flight hours. It is suspected that in some cases failures of the hoist control box were responsible for incidents reported as winch failures. Rapid reversals of winch direction caused burnout of the control box, and a time delay relay has been added to eliminate this mode. The winch brake has exhibited an overheating problem associated with descending loads greater than 300 lb in rescue hoist operation. (The hoist winch is rated at 600 lb). However, current rescue operations utilize a hydraulic rescue hoist installation, for which a similar problem was alleviated by increasing winch oil quantity.

### C. Self-Loading Hook

Most failures of the self-loading hook are associated with internal moisture and corrosion. This condition was caused by aircraft water operation with the hook installed (the hook was not designed for operation in a water environment). In addition, the method of stowing electrical and mechanical release cables frequently permitted these cables to contact the ground on taxiing, resulting in subsequent malfunctions of the release system(s). This problem was corrected by revising the hook release cable stowage configuration.

## DESCRIPTION OF DATA AND SOURCES

### DATA

Data was accumulated on the following helicopter models and types. Corresponding flight time and calendar period are noted:

<u>Aircraft Type</u>	<u>Flight Time (hr)</u>	<u>Calendar Period</u>
CH-54A	48,000	January 1968 thru Sept 1970
CH-54B	2,400	April 1971 thru March 1972
CH-53A	68,457	August 1967 thru March 1970
CH-53D	35,000	October 1969 thru March 1971
CH-53C & HH-53B/C (Rescue Hoist Only)	38,366	January 1968 thru March 1971
CH-3C/E & HH-3E	104,000	January 1965 thru Dec. 1968

### DATA SOURCES

A breakdown of data sources by aircraft type is as follows:

<u>Aircraft Type</u>	<u>Data Source</u>
CH-54A/B	Discrepancy/Corrective Action Reports (DCAR); Army ORME Program
CH-53A/D	Navy 3M Data Program
CH-53C, HH-53B/C, CH-3C/E, HH-3E	Air Force 66-1 Data Program

Note that data sources differ in content as follows:

Army ORME Program (CH-54A/B) - all failures

Navy 3M Program (CH-53A/D) - all failures

AF 66-1 Program (CH-53C, HH-53B/C, CH-3C/E &  
HH-3E) - all failures. EMT not required.

For all sources, maintenance time is reported only for organizational and intermediate levels.

CARGO SYSTEMS INVESTIGATED

Cargo Hooks and Releases  
Cargo & Rescue Hoists & Winches  
Cargo Hoist Cables  
Slings (CFE)  
Decouplers  
Pendants  
Rollers, Sheaves, Conveyers  
Cargo Handling Power Systems  
Instrumentation  
Controls  
Cargo Restraint and Tie-Downs  
Rigging Points  
Guillotines

## ABBREVIATIONS AND TERMS USED IN TABLE V

Failure - An unsatisfactory condition that results when an item operating or performing its function in a useful environment ceases to operate or operates outside of established limits.

Abort Failure - A failure which prevents completion of launch of a mission, either by rendering the system incapable of performing the primary function of the mission or by exposing the occupants to unacceptable flight risk if the mission is continued or launched.

Abort Rate - Number of abort failures per hour of flight time (flight-hour).

Mean-Time-Between-Failures (MTBF) - The total flight time divided by the number of failures occurring during this time interval.

Man-Hour - A unit consisting of an elapsed hour during which one technician is actively engaged in performance of a corrective or preventive maintenance action.

Elapsed Maintenance Time (EMT) - Maintenance clock time in hours and tenths of an hour without adjustment for more than one technician working concurrently.

Mean Man-Hours Per Failure (Mean Man-Hr/Fail) - The total man-hours required due to a given mode or group of failure modes divided by the total number of incidents of failure.

Mean Elapsed Maintenance Time Per Failure - The total number of elapsed maintenance hours due to a given failure mode or group of failure modes divided by the total number of incidents of failure.

Mean Man-Hours Per Flight Hour (Mean Man-Hr/FH) - The total man-hours required due to a given mode or group of failure modes divided by the total flight time accumulated on the components involved during the period in which the incidents of failure occurred.

## IMPACT CATEGORIES

For all aircraft types considered, failure modes are classified in one or more of the following impact categories:

- 1) Safety of Flight - Failures in this category suggest a potential to produce a hazardous flight condition.
- 2) Mission & System Reliability - Failures based on primary modes which prohibited achievement of target objectives. Expressed here in terms of aborts & abort rate.
- 3) Operational Environmental Effects - Failures attributed to hardware/environment incompatibility.
- 4) Maintenance - Failure modes for which:
  - a) MTBF is less than 10,000 hours
  - b) Mean Maintenance Hours Per Flight Hours exceeds .0002

Note that for cargo handling systems, the actual time of component operation is considerably less than flight time. As used in this report, MTBF is intended only as a relative measure for comparing incidence of failure. This qualification also applies to all other parameters based on flight time.

FUNCTIONAL DESCRIPTION OF CARGO SYSTEM COMPONENTS  
COVERED IN APPENDIX II

CH-54A/B

Cargo Hoist Cable Assembly - Load-carrying cable for single-point system. Includes internal electrical wires associated with cockpit indicators and hook release circuitry.

Cargo Hook Swivel Assembly - Permits rotation of cargo hook about hoist cable assembly. Also provides electrical junction between hoist cable assembly and hook.

Cargo Hook Release Assembly - Single-point system load-carrying hook. May be released electrically from the cockpit or manually at the hook.

Decoupler - Installed between cargo hoist drum and fuselage. Isolates single-point load from helicopter vibration. On the CH-54A aircraft, the decoupler measures loads over 10,000 lb from cockpit readout, and decoupler recharge is effected through a charging switch. On the CH-54B aircraft, the decoupler measures loads of all magnitudes, and recharge is automatic at engine start.

Hoist Pump - A variable-flow, pressure-demand pump mounted in the accessory section of the main gearbox and driven by the main gearbox.

Hydraulic Four-Way Solenoid-Operated Hoist Control Valve (CH-54A Only) - Mounted on hoist panel, forward hoist well. Controls direction of cargo hoist. When hoist is not in use, the valve blocks the hoist up line, creating a hydraulic lock and assisting the hoist brake in supporting the load.

Hoist Brake Servo Valve - Mounted on hoist panel, forward hoist well. When actuated, directs 400-psi hydraulic pressure to release hoist brake. When released, the valve vents the hoist brake system to return, allowing the hoist brake to engage.

Cargo Lashing Peel Cable Release Cylinder (CH-54A Only) - Permits locking/unlocking of cargo lashing reels.

Load-Leveler Cylinder - Permits raising or lowering of four-point load, as well as leveling.

Controlex - Load-leveler control cables (CH-54A only).

CH-53A/C/D and HH-53B/C

External Cargo Hook - Mounted on attachments in cargo hook well, below helicopter c.g. May be released automatically on touchdown, or electrically from the cockpit or crewman's pistol grip release. Mechanical release also possible from cockpit or at the hook.

Cargo Hook Access Door Assembly - A hinged panel located near center of cargo floor, under which the hook is stowed. Access door is opened by lifting and turning a handle recessed in the door.

Cargo Winch Assembly - Two winches per aircraft at front of cargo compartment floor to facilitate loading and unloading of cargo.

Cargo Winch Controllable Hydraulic Pump - Provides hydraulic power to drive winch motor.

Winch Control Pendant - Provides for crewman control of winches.

The following components are included in H-53 aircraft equipped with rescue hoist.

Manual Control Valve - Permits variation of hoist speed from cabin, when hoist control panel mode selector switch is in CREW position.

Flow Control Valve (Regulator, Two per aircraft) - Provides correct hydraulic fluid flow to four-way direction control valve. One regulator operated with the hoist panel control mode selector switch in the PILOT position, and the other operates with the switch in the CREW position.

Four-Way Directional Control Valve - Controls direction of rotation of hydraulic motor.

Three-Way Flow Control Valve - Provides hydraulic pressure from utility system to high-speed or low-speed regulator, depending on position of mode selector switch.

### CH-3C/E and HH-3E

Cargo Loading and Rescue Hoist Winch Installation - Consists of a single winch, mounted in the left front corner of the cargo compartment and used for either cargo loading or rescue operations. The winch is electrically controlled via a hoist control box assembly. In the rescue mode, a removable truss support is installed and the winch cable reeved through a system of snatch blocks and receiver. A power reel unit is mounted on the truss support, to maintain tension on the cable as it is paid out.

Winch Pendant Control - A portable speed control device for remote control operation of the winch. The pendant may have either a 10-foot cable integral to the pendant or a 25-foot coil type connected with a screw type fitting. The pendant cable may be connected to receptacles for either cargo winch or rescue hoist operation.

High-Speed Rescue Hoist Installation - A variable-speed hydraulic hoist winch suspended on a fixed truss over the personnel door. The winch motor is powered by the utility hydraulic system. The system includes a simple open-throat stainless steel hook for attaching rescue equipment.

External Cargo Hook - Attached to a stowage pickup line at bottom of fuselage. May be used with either conventional or low-response type cargo slings. Releases loads electrically, manually, or automatically.

TABLE V. SIKORSKY CARGO HANDLING SYSTEM COMPONENT RELIABILITY

TABLE V. SIKORSKY CARGO HANDLING SYSTEM COMPONENT RELIABILITY										
CH-53A-(Army) Single-Point System				48,000 January 1968 - September 1970				Flight Hours		
Nomenclature	P/N	Fail Mode/No.	MTRF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EMT	Mean Man-Hr/Fail	Mean M-Hr/Fail X 10 <sup>3</sup>	Impact Category
Cargo Hoist Cable Assembly (Main Hoist Cable)	S6090-62356-2 S6435-63090-101 -102/-105	Hook Release Inop/Open or Short in Cable/14	3,430	3	6.3	31.4	114.5	22.4	8.2	
		Hook Unhook Light Inop/Open or Short in Cable/4	12,000	0	0	24.4	15.4	6.1	3.9	
		Release Inop. Cause Unknown	6,000	3	6.3	125.5	56.8	15.7	7.1	
		Backlash Kinked, Loose on Drum/22	2,180	3	6.3	183.3	77.3	8.3	3.5	
		Loose, Broken Strands/4	12,000	0	0	86.1	47.5	21.5	11.9	
Cable Assembly Totals			52	923	9	18.9	733.3	14.1	4.15	15.3
Cable Assembly (Swivel to Hook Assembly)			SP 2948-2							
		Broken Wire in Plug/4	12,000	0	0	4.8	4.8	1.2	1.2	
		Plug Corroded, Wet/2	24,000	0	0	1.7	1.7	0.9	0.9	
Cable Assembly Totals			6	6,000	0	6.5	6.5	1.1	1.1	0.1
Cargo Hook Swivel Assembly	6450-62106-103	Hook Release Inop/Contamination Slip Rings/27	1,780	3	6.3	73.0	68.6	2.7	2.5	
		Binding, Won't Rotate Freely/9	5,330	2	4.2	23.3	20.8	3.0	2.3	
		Hook Unhooked Light Remains On/Moisture Contamination/14	3,430	1	2.1	44.3	35.3	3.2	2.5	

TABLE - Continued

CH-54A (Army Single-Point System (Cont.))										
Nomenclature	P/N	Fail Mode/ Ho.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EMT	Mean Man-Hr/Fail	Mean EMT/Fail X 10 <sup>3</sup>	Impact Category
Cargo Hook (Cont.)										
Swivel Assembly										
		Hook Release Inop/Open at Slip Ring/3	16,000	0	0	7.2	5.2	2.4	1.7	
		Other/3	16,000	1	2.1	3.1	2.6	1.0	0.9	
Swivel Assembly Totals										
		56	856	7	14.6	150.9	132.5	2.7	2.4	2,3,4
Cargo Hook										
Release Assembly										
	64500-62100-101/-102/-103	Burr On Beam Release/6	8,000	1	2.1	72.5	32.5	12.1	5.4	
		Faulty Latch/12	4,000	1	2.1	50.8	25.0	4.2	2.1	
		Insufficient Latch Radius/3	16,000	0	0	15.0	12.0	5.0	4.0	
		Hook Internal Fail/6	8,000	2	4.2	17.9	10.4	3.0	1.7	
		Hook Dirty, Full of Water, or Contaminated/4	12,000	2	4.2	8.0	7.0	2.0	1.8	
Hook Release Assembly Totals										
		31	1,550	6	12.5	164.2	86.9	5.3	2.8	2,3,4
Hoist Assembly										
	5435-63000-015/-018/-019	Shear Pin Sheared/8	6,000	4	8.4	28.8	17	3.6	2.1	
		Hoist Would Not Pivot On Drum Axis/1	48,000	0	0	20.0	9.0	20.0	9.0	
Brg. (Matched Set) Drum Mount Brg.										
	SB15554-2	Mode Unknown/1	48,000	0	0	60.0	16.5	60.0	16.5	
Variable Resistor (Cable Length Indicator)										
	SB055-62019	Inop. Stuck/8	6,000	0	0	13.7	12.2	1.7	1.5	
Cable Guide Assembly										
	6435-63087-101 SB035-63033	Worn/29	1,780	0	0	37.0	30.5	1.3	1.1	
Hoist Assembly Totals										
		47	1,020	4	8.4	159.5	85.2	3.4	1.8	2,4

TABLE V - Continued										
CH-54A (Army) Single-Point System (Cont.)										
Nomenclature	P/N	Fail Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EXT	Mean Man-Hr/Fail	Mean EXT/Fail X 10 <sup>3</sup>	Impact Category
Cable Limit Switches (1 ea. up & down)	21EN12-12	Loss of Adjustment Due to Vibration & Wear of Working Surfaces/12	8,000	0	0	9.6	9.0	0.8	0.7	
		Int. Failures/3	32,000	0	0	3.8	2.9	1.3	1.0	
		Limit Switch Totals	15	6,400	0	0	13.4	11.9	0.9	0.8
Decoupler	6450-62352-102/-103/-104	Leaking, Seal Failures/23	2,090	1	2.1	88.6	3.9	2.1		
		Load Indicator Inop/4	12,000	0	0	10.8	5.4	2.7	1.4	
Decoupler Totals		27	1,780	1	2.1	99.4	53.9	3.7	2.0	2.4
Hoist Pump	6465-200C1-101	Leaking, Seal Fail/6	8,000	0	0	21.4	14.2	3.6	2.4	
		Inop. Internal Failure/5	9,600	1	2.1	31.2	18.6	6.2	3.7	
		Improper Press. Output/21	2,280	2	4.2	223.9	107.8	10.7	5.1	
		Internal Elec. Fail/5	9,600	2	4.2	33.5	15.0	6.7	3.0	
Hoist Pump Totals		37	1,300	5	10.4	310.0	155.6	8.4	4.2	6.5
Hydraulic Four Way Solenoid Operated Hoist Control Valve	1974G-1	Internal Failure/9	5,330	4	8.4	125.3	62.5	15.9	6.9	2.4
		Hoist Brake Servo Valve	217363-01	Internal Failure/8	6,000	1	2.1	26.4	20.4	3.3

TABLE V - Continued										
CH-54. (Army) Four-Point System										
Nomenclature	P/M	Fail Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EMT	Mean Man-Hr/Fail	Mean EMT/Fail X 10 <sup>5</sup>	Impact Category
Cargo Lashing	6465-61402-041	Leaking/4	12,000	0	0	8.5	8.5	2.1	2.1	
Reel Cable		Internal Failures/2	24,000	0	0	4.2	2.7	2.2	1.4	
Release Cylinder										
Cylinder Totals		6	8,000	0	0	12.7	11.2	2.1	1.9	1
Controlex	5220086-1/-2/-3/-4	Bound Up/3	64,000	0	0	19	11.5	6.3	3.8	
	(1 ea. per A/C)									
		Out of Adjustment (Vibration)/5	36,000	0	0	7.9	5.8	1.6	1.2	
		Contamination/5	38,400	0	0	19	9.5	3.8	1.9	
Controlex Totals		13	14,800	0	0	45.9	26.8	3.5	2.1	3,1

TABLE V - Continued											
CH-54B (Army) Single-Point System			2400 Flight Hours April, 1971 - March, 1972								
Nomenclature	P/N	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10	Max - Hr	EMT	Mean Man-Hr/Fail	Mean EMT/Fail	Mean M-H/PH X 10	Impact Category
Guide & Feed Screw Assembly	6485-64200-042	Contaminated Bearings/1	2,400	0	0	31.0	23.0	31.0	23.0	12.9	4
Liner Assembly	6485-64204-106	Worn/4	600	0	0	2.8	2.8	0.7	0.7	1.2	4
Decoupler	6485-64500-102	End Plate Or Housing Failure/9	267	3	125.0	64.1	38.6	7.1	4.3		
		Leaking/2	1,200	0	0	21.0	10.5	10.5	5.3		
Decoupler Totals		11	218	3	125.0	85.1	49.1	7.7	4.5	35.5	2,4

TABLE V - Continued											
CH-53A (Navy)											
68,500 Flight Hours August 1967 - March 1970											
Nomenclature	P/N	Fail Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man - Hr	EXT	Mean Man-Hr/Fail	Mean EXT/Fail	Mean M-H/Fail X 10 <sup>5</sup>	Impact Category
External Cargo Hook	65375-04500-101	Fail To Op/3	22,800	0	0	13.0	7.0	4.3	2.3		
		Broken/3	22,800	0	0	6.5	4.0	2.2	1.3		
		Won't Engage/1	68,500	1	1.5	4.0	2.0	4.0	2.0		
		Other/5	13,700	0	0	11.0	5.0	2.2	1.0		
Cargo Hook Totals		12	5,700	1	1.5	34.5	18.0	2.9	1.5	0.5	2,3,4
Cargo Hook Access Door Assembly	65207-04001-081	Torn/2	34,250	0	0	6.0	6.0	3.0	3.0		
Door Structure											
		Loose/1	68,500	0	0	13.3	9.3	13.3	9.3		
		Distorted/3	22,800	0	0	53.4	53.4	17.8	17.8		
		Delaminated/9	7,610	0	0	149.0	147.0	16.6	16.3		
		Punctured/3	22,800	0	0	37.0	31.0	12.3	10.3		
		Adjusted Improperly/1	68,500	0	0	12.5	12.5	12.5	12.5		
Door Structure Totals		19	3,600	0	0	271.2	259.2	14.3	13.6		
Hook Access Door Handle		Broken/21	3,260	0	0	30.7	30.2	1.4	1.4		
Cargo Hook Access Door Assembly Totals		40	1,710	0	0	301.9	289.4	7.6	7.2	4.4	4

TABLE V - Continued											
CH-53A (Navy) (Cont.)											
Nomenclature	F/N	Fail Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EMI	Mean Man-Hr/Fail	Mean EMI/Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category
Cargo Winch Assembly	65460-02100-104	Fail to Op/4	34,200	0	0	8.0	5.5	2.0	1.4		
		Broken/8	17,100	0	0	28.8	21.3	3.6	2.6		
		Broken Ground Wire/1	137,000	0	0	3.0	3.0	3.0	3.0		
Winch Assembly Totals	13		10,540	0	0	39.8	29.8	3.1	2.3	0.3	4
Cargo Winch Controllable Hydraulic Pump	64402001-1 (65453-09021-102)	Fail to Op/32	2,140	11	16.1	469.4	260.1	14.7	8.1		
		Binding/3	22,800	1	1.5	14.4	14.4	4.8	4.8		
		Broken/2	34,250	0	0	29.2	14.6	14.6	7.2		
		Leaking/26	2,630	5	7.3	388.2	212.3	14.9	8.2		
		Incorrect Pressure/4	17,150	1	1.5	108.2	63.2	27.1	15.8		
		Cracked/4	17,150	0	0	27.5	14.5	6.9	3.6		
		Internal Failure/11	6,230	2	2.9	129.1	57.6	11.7	5.2		
		Eurst/5 (Cracked)	13,700	2	2.9	63.2	37.2	12.6	7.4		
		Other/7	9,800	2	2.9	114.1	68.6	16.3	9.8		
Winch Hydraulic Pump Totals	94		728	24	35.0	1343.3	742.5	14.3	7.9	19.7	2,4
Pendant	21663-2	Broken/62	1,100	0	0	118.4	94.3	1.9	1.5		
		Fail to Op/7	9,780	0	0	11.0	8.5	1.6	1.2		
		Broken Housing/2	34,250	0	0	6.0	6.0	3.0	3.0		
		Cracked/2	34,250	0	0	3.0	2.0	1.5	1.0		
		Other/5	13,700	0	0	4.4	4.4	0.9	0.9		
Pendant Totals	76		678	0	0	141.7	115.2	1.8	1.5	2.1	4

TABLE V - Continued

		35,000 Flight Hours October 1969 - March 1971 Data From Navy 36 Program									
Nomenclature	P/N	Failure Mode/No.	MBSF	No. Abort	Abort Rate X 10 <sup>5</sup>	Man - Hr	EMT	Mean Man-Hr/Fail	Mean EMT/Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category
Cargo Hook (External)	65375-04500-101	Broken/6	4,380	0	0	7.4	6.4	.93	.8		
		Internal Failures/4	8,750	1	3.0	6.8	5.8	1.7	1.5		
		Other/6	5,840	0	0	6.3	6.3	1.1	1.1		
Cargo Hook Totals		18	1,940	1	3.0	20.5	18.5	1.1	1.0	0.6	2,3,4
Cargo Hook Access Door Assembly	65207-04001-081	Delaminated/5	7,000	0	0	6.5	6.5	1.3	1.3		
		Distorted/1	35,000	0	0	2.0	2.0	2.0	2.0		
Access Door Totals		6	5,885	0	0	8.5	8.5	1.4	1.4	0.2	4
Cargo Winch Assembly	65360-03100-104	Broken Fail to Operate/E	8,750	0	0	28.5	25.5	3.6	3.2		
Hydraulic Motor	53FE01005-1	Distorted/1	70,000	0	0	1.0	1.0	1.0	1.0		
		Leaking/1	70,000	0	0	1.5	1.5	1.5	1.5		
Winch Assembly Totals		11	6,360	0	0	31	30	3.2	2.7	0.4	4
Cargo Winch Controlable Hydraulic Pump	64WH08001-1	Internal Failure, Fail to Operate/22	1,590	7	20.0	124.1	60.8	5.2	2.8		
		Leaking/10	3,500	1	2.9	84.0	53.0	8.4	5.3		
		Sheared/2	17,500	0	0	54.0	31.0	27.0	15.5		
		Other/3	11,700	0	0	15.5	10.5	5.2	3.5		
Hydraulic Pump Totals		37	945	8	22.8	267.6	155.3	7.3	4.2	7.7	2,4
Cargo Winch Controlable Hydraulic Pump	65055	Fail to Operate/2	17,500	1	2.9	16	8	8	4		
		Leaking/5	7,000	0	0	51	21	10.2	4.2		
Hydraulic Pump Totals		7	5,000	1	2.9	67	29	9.5	4.2	1.9	2,4

TABLE V - Continued

CH-53D (Navy) (Cont.)		F/N		Failure Mode/No.	WTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	EMT	Mean Man-Hr/Fail	Mean EMT/Fail	Mean M-H/PH X 10 <sup>3</sup>	Impact Category
Nomenclature													
Winch Control Pendant	21663-2			Broken Inop/4	6,750	0	0	43.7	10.7	10.9	2.7		
Button Trigger Switch Assembly	21341 21792	Same Event		Missing/1 { Poor Contact/1	35,000	0	0	1.5	1.5	1.5	1.5		
Receptacle	21758			Distorted/2	35,000	0	0	3.0	3.0	3.0	3.0		
Pendant Totals		6			5,830	0	0	40.2	15.2	6.0	2.5	1.4	1

TABLE V - Continued									
CH-53C and HH-53B/C Rescue Hoist System (Air Force)									
38,366 Flight Hours January 1968 - March 1971									
Nomenclature	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man- Hr	Mean Man-Hr /Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category	
Guillotine Circuit Tester	Broken/3	12,800	0	0	3.5	1.7			
	Loose Hardware/3	12,800	0	0	2.9	1.0			
	Broken Safety Wire/33	1,160	0	0	16.4	5.0			
	Loose/4	9,600	0	0	2.1	0.5			
	Other/3	12,800	0	0	4.3	1.4			
Guillotine Circuit Tester Totals	46	856	0	0	29.2	0.6	0.8	4	
Hoist Control Panel	Broken Safety Wire/28	1,370	0	0	4.1	0.2			
	Leaking/27	1,420	0	0	79.2	2.9			
	Loose/3	12,800	0	0	1.5	0.4			
	Other/5	7,675	0	0	10.8	2.2			
	Control Panel Totals	63	0	0	95.4	1.5	2.5	4	
Support	Worn/2	19,200	0	0	7.5	3.8			
	Missing Hardware/2	19,200	0	0	3.0	1.5			
	Not to Specification/1	38,400	0	0	9.0	9.0			
	Other/5	7,675	0	0	6.3	1.3			
	Support Totals	10	0	0	25.8	2.6	0.7	4	
Manual Control Valve	Leaking/19	2,020	0	0	111.7	5.9			
	Internal Failures/2	19,200	0	0	9.0	4.5			
	Broken Safety Wire/12	3,200	0	0	6.1	0.5			

TABLE V - Continued

CH-53C and HH-53B/C Rescue Hoist System (Air Force) (Cont.)							
Nomenclature	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr/Fail	Mean M-H/PH X 10 <sup>3</sup>	Impact Category
Manual Control Valve (Cont.)	Missing Hardware/4	9,600	0	0	0.4		
	Other/10	3,840	0	0	14.3	1.4	
Manual Control Valve Totals	47	817	0	0	142.5	3.0	4
Flow Control Valve (Regulator) (2 per A/C)	Leaking/5	15,350	0	0	23.8	4.8	
	Hoist Overspeed/2	38,400	0	0	2.5	1.3	
	Other/5	15,350	0	0	1.6	0.3	
Flow Control Valve Totals	12	6,410	0	0	27.9	2.3	4
4-Way Directional Control Valve	Leaking/5	4,800	0	0	16.5	2.1	
	Broken Safety Wire/16	2,400	0	0	9.1	5.7	
	Internal Failure/4	9,600	0	0	27.0	6.8	
	Other/3	12,800	0	0	7.6	2.5	
4-Way Valve Totals	31	917	0	0	60.2	1.9	10, 4
3-Way Flow Control Valve	Leaking/3	12,800	0	0	7.2	2.4	
	Broken Safety Wire/9	4,260	0	0	12.6	1.4	
3-Way Valve Totals	Improper Adjustment/1	38,400	0	0	15.0	15.0	
	Other/5	7,675	0	0	11.3	2.3	
	16	2,130	0	0	46.1	2.6	1.2 10, 4
Accumulator	Leaking/1	38,400	0	0	9.5	9.5	
	Incorrect Pressure/7	5,500	0	0	15.5	2.2	
* Potential Hazard to Rescue Victim							

TABLE V - Continued

TABLE V - Continued								
CH-53C and HH-53B/C Rescue Hoist System (Air Force) (Cont.)								
Nomenclature	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man - Hr	Mean Man-Hr/Fail	Mean M-H/FH X 10 <sup>5</sup>	Impact Category
Accumulator (Cont.)								
	Broken Safety Wire/11	3,490	0	0	6.9	6.3		
	Internal Failures/1	38,400	0	0	9.0	9.0		9
	Other/9	4,260	0	0	9.1	1.0		
Accumulator Totals	29	1,330	0	0	50.0	1.7	1.3	4
Rescue Hoist								
	Worn/4	9,600	0	0	1.3	0.3		
	Broken/2	19,200	0	0	9.4	4.7		
	Loose Hardware/7	5,500	0	0	5.3	7.6		
	Missing Hardware/5	7,675	0	0	3.1	0.6		
	Broken Safety Wire/8	4,800	0	0	3.3	0.4		
	Improper Adjustment/1	38,400	1	2.6	1.3	1.3		
	Corroded/8	4,800	0	0	7.9	1.0		
	Fail to Operate/6	6,400	0	0	34.3	5.7		
	Open/2	19,200	0	0	7.6	3.8		
	Leaking/	19,200	0	0	20.5	10.3		
	Loose/7	5,480	0	0	18.6	2.7		
	Other/7	5,480	0	0	12.9	1.8		
Rescue Hoist Totals	59	650	1	2.6	125.5	2.1	3.3	1*,2,4
*Potential Hazard to Rescue Victim								

TABLE V - Continued

TABLE V - Continued								
CH-53C and HH-53E/C Rescue Hoist System (Air Force) (Cont.)								
Component	Failure Mode/ No.	MTEF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man - Hr	Man-Hr / Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category
Hoist Winch	Worn/2	19,200	0	0	9.4	4.7		
	Broken/1	36,400	0	0	20.0	20.0		
	Loose Hardware/5	7,675	0	0	5.1	1.0		
	Adjusted Improperly/1	36,400	0	0	20.0	20.0		
	Corroded/2	1,800	0	0	7.6	0.9		
	Distorted/1	36,400	0	0	27.7	27.7		
	Other/3	12,800	0	0	2.3	0.8		
Winch Totals	21				92.1	4.4	2.4	1 <sup>a</sup> , 4
Hydraulic Motor	Worn/2	19,200	0	0	1.5	0.8		
	Adjusted Improperly/1	36,400	0	0	7.2	7.2		
	Binding/1	36,400	0	0	4.5	4.5		
	Other/7	5,500	0	0	3.2	4.6		
	11	3,490	0	0	16.4	1.5	0.4	1 <sup>a</sup> , 4
Limit Switch (3 per A/C)	Worn/2	36,400	0	0	2.0	1.0		
	Broken/1	115,000	0	0	12.0	12.0		
	Broken Safety Wire/7	16,500	0	0	2.8	0.4		
	Adjusted Improperly/10	11,500	0	0	50.0	5.1		
	Binding/2	57,900	0	0	4.0	2.0		
	Fall to Operate/2	57,500	0	0	5.0	2.5		
	Other/10	11,500	0	0	16.6	1.7		
Limit Switch Totals	34	3,380	0	0	92.9	2.7	0.8	4
Potential Hazard to Rescue Victim								

TABLE V - Continued									
CH-53C and HH-53B/C Rescue Hoist System (Air Force) (Cont.)									
Nomenclature	Failure Mode/ No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man - Hr	Mean Man-Hr /Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category	
Hoist Cable	Worn/12	3,200	0	0	85.9	7.2			
	Broken/7	5,500	0	0	48.6	7.0			
	Distorted/4	9,600	0	0	19.7	4.9			
	Other/11	3,490	0	0	21.7	2.0			
Hoist Cable Totals	34	1,130	0	0	175.9	5.2	4.6	1*	4
Rescue Hook	Adjusted Improperly/3	12,800	0	0	8.3	2.8			
	Corroded/9	4,260	0	0	8.5	0.9			
	Broken Safety Wire/5	7,675	0	0	6.1	1.2			
	Missing Hardware/3	12,800	0	0	1.7	0.6			
	Other/11	3,490	0	0	15.7	1.4			
Rescue Hoist Totals	31	1,240	0	0	40.3	1.3	1.1	1*	4
*Potential Hazard to Rescue Victim									

TABLE V - Continued									
CH-3C/E and HH-3E (Air Force)		104,000 Flight Hours January 1965 - December 1968							
Nomenclature	P/N	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	Mean Man-Hr/Fail	Mean M-H/PH X 10 <sup>3</sup>	Incident Category
<b>Cargo Loading &amp; Rescue Hoist Winch Installation (all CH-3C/E)</b>									
<b>Winch Assembly</b>									
	S6152-62350-2	Shorted/3	34,700	0	0	5.7	1.9		
		Worn/15	6,940	0	0	65.5	4.5		
		Burned/5	20,800	0	0	32.3	6.5		
		Fail to Operate/8	13,000	0	0	37.2	4.7		
		Internal Failure/19	5,470	1	1.0	40.5	2.1		
		Stripped/3	34,700	0	0	12.8	4.3		
		Broken/8	13,000	0	0	25.5	3.2		
		Other/7	14,900	0	0	40.3	5.7		
<b>Winch Assembly Totals</b>		68	1,530	1	1.0	259.8	3.8	2.5	1*2,4
<b>Hoist Control Box Assembly (Used w/Cargo/Rescue Hoist Installation)</b>									
	BL-702	Internal Failure/21	4,950	0	0	62.1	3.0		
		Fail to Operate/11	9,450	0	0	38.9	3.5		
		Defective Contact/5	20,800	0	0	12.3	3.5		
		Shorted/5	20,800	0	0	38.7	7.7		
		Open/4	26,000	0	0	30.4	7.6		
		Burned/18	5,760	0	0	132.2	7.3		
		Incorrect Voltage/1	104,000	0	0	6.3	6.3		
<b>Hoist Gearbox Totals</b>		65	1,600	0	0	320.9	5.0	3.1	1*2,4
*Potential Hazard to Rescue Victim									

TABLE V - Continued									
CH-53C/E and HH-3E (Air Force) (Cont.)									
Nomenclature	P/N	Failure Mode/No.	MTBF	No. Aborts	Abort Rate, X 10 <sup>5</sup>	Man-Hr	Mean Man-Hr/Fail	Mean M-E/FH X 10 <sup>9</sup>	Impact Category
Winch Pendant Control (For Use w/Cargo Rescue Hoist)	BL4701-1 (S6157-61061-1)	Broken/2	52,000	0	0	4.6	2.3		
		Improper Adjustment/5	20,800	0	0	14.0	2.8		
		Internal Failure/2	52,000	0	0	8.7	4.4		
		Other/6	17,350	0	0	15.2	2.5		
BL4701-1 Pendant Totals		15	6,940	0	0	42.5	2.8	0.4	4
	BL5991	Broken/2	52,000	0	0	7.0	3.5		
		Defective Contact/2	52,000	0	0	3.5	1.8		
		Worn/2	52,000	0	0	4.0	2.0		
		Internal Failure/13	8,000	0	0	23.5	1.8		

TABLE V - Continued									
CH-3C/E and HH-3E (Air Force) (Cont.)									
Nomenclature	P/N	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	Mean Man-Hr/Fail	Mean M-H/FH X 10 <sup>3</sup>	Impact Category
BL5991 Pendant (Cont.)		Open/3	34,700	0	0	5.8	1.9		
		Other/5	20,800	0	0	10.8	2.2		
BL5991 Pendant Totals		27	3,850	0	0	54.6	2.0	0.5	4
Power Reel (For Cargo/Rescue Hoist Used in Rescue Mode)	BL6300 (S6152-62366-1)	Stripped/1	104,000	0	0	11.0	14.0		
		Failed to Operate/2	52,000	0	0	3.0	1.5		
		Internal Failures/2	52,000	0	0	3.0	1.5		
		Burned/1	104,000	0	0	1.0	1.0		
Power Reel Totals		6	17,300	0	0	21.0	3.5	0.2	4
High-Speed Rescue Hoist Installation	S6152-62380-1 S6152-62380-4								
Winch Assembly	S6152-62381-1	Worn/3	34,700	0	0	21.0	7.0		
		Internal Failures/1	104,000	0	0	1.3	1.3		
		Distorted/1	104,000	0	0	4.0	4.0		
		Leaking/1	104,000	0	0	1.0	1.0		
		Broken/1	104,000	1	1.0	0.5	0.5		
		Loose Hardware/1	104,000	0	0	2.2	2.2		
Winch Assembly Totals		8	13,000	0	0	30.0	3.8	0.3	1*,2,4
*Potential Hazard to Rescue Victim.									

TABLE V - Continued									
CH-3C/E and HH-3E (Air Force) (Cont.)									
Nomenclature	P/N	Failure Mode/No.	MTBF	No. Aborts	Abort Rate X 10 <sup>5</sup>	Man-Hr	Mean Man-Hr/Fail	Mean M-H/FH X10 <sup>3</sup>	Impact Category
Fairing Assembly	S6122-87277-2 (Consists of -3/-4/-5 Fairings)	Cracked/4	78,000	0	0	24.2	6.0	0.2	4
Self-Loading Hook (Used in Both Conventional & Low Response Slings)	S6152-62100-1 (SF7086-1)	Internal Failures/7	14,900	0	0	15.6	2.2		
		Failed to Operate/13	8,000	0	0	40.6	3.1		
		Contaminated/14	7,440	0	0	65.0	4.6		
		Shorted/2	52,000	0	0	7.0	3.5		
		Corroded/3	34,700	0	0	12.0	4.0		
		Improper Adjustment/5	20,800	0	0	20.5	4.1		
		Broken/7	14,900	0	0	23.4	3.4		
		Worn/4	26,000	0	0	12.9	3.2		
		Resistance Incorrect/6	17,300	0	0	15.3	2.5		
		Other/14	7,440	0	0	57.7	4.1		
Self-Loading Hook Totals	75					270.0	3.6	2.6	3.4

APPENDIX III  
SUMMARY OF WORK PERFORMED UNDER  
CONTRACT DAAJ02-72-C-0037

The following is a summary of the work performed under the subject contract.

Task I - Scope Definition

In accordance with this task, the VTOL cargo handling systems to be covered by this contract were defined. They included:

- Instruments, controls, and displays
- Power systems
- Hoists and winches
- Load isolators
- Rigging points
- Emergency release devices
- Hoisting and winching cables
- Pendants
- Cargo hooks
- Slings
- Nets
- Pallets, pods, and containers
- Rollers and sheaves
- Cargo restraints
- Hoist and winch systems
- Positioning hoist systems
- Multiple-point hoist systems

The scope of this study was sufficiently broad to make the results reported herein applicable to most cargo handling system designs presently in use in the helicopter industry and those anticipated in the foreseeable future. Items not covered in this report include:

- Common cargo handling components, such as shackles, for which widely accepted test procedures already exist.
- Excessively specialized components, such as davits, booms, and specialized winches, which have seen limited application in helicopter cargo handling systems.

- Common aircraft components such as fasteners, controls, instruments, etc., for which satisfactory qualification test methods already exist. Component-level tests for these items are not included here; however, in most cases these items will be subjected to testing at the system level along with the rest of the particular test item. For completeness, some such items are identified in the text of this report (controls, instruments, displays, and power systems).

## Task II - Documentation

During performance of this task, military, FAA, and industry test specifications and test reports were reviewed to explore present qualification test methods and possible alternative test methods. The test specifications and reports reviewed and their applicability are summarized in Table VI. It was generally noted in reviewing the test specifications that each individual test method within a qualification test program was designed to test a specific failure mode, e.g., structural-static, structural-fatigue, corrosion, high temperature, etc., and that most test programs made no attempt to test interrelated failure modes, e.g., sand and dust/endurance, rough handling/immersion tests, etc. Noted also in reviewing the test specifications and reports were inconsistencies in component testing. Some (such as variations in sling endurance strength testing methods) are due to limitations in the testing state of the art. Other differences in qualification test methods and test philosophies appear to be a lack of application of the most up-to-date test methods. Finally, it was noted that on occasion possible and even probable failure modes were not tested at all.

In conjunction with Task II, a comprehensive survey of reliability and maintainability data for Sikorsky cargo handling systems and components was made. The data obtained and their sources are presented in Appendix II. It was noted while reviewing the R&M data that most failures which occurred in significant numbers appeared to be combined-cause or cascaded-cause failures; that is, the combined simultaneous effects of different factors such as wear and sand and dust appeared to be a cause of many hydraulic seal failures. In other cases, the sequential effects of environments combined to cause failures; e.g., a cargo hook might be damaged by impact such that, although still functioning, it will be susceptible to sand and dust and moisture damage. The need for combined effects testing is indicated. Few cases were found of frequent failures by modes which were tested during component qualification. This indicates that adequate qualification testing does assure component reliability when

the significant failure modes are tested. For the limited data of that type that was available, it was found that there was often satisfactory agreement between MTBFs encountered during combined environment testing and MTBFs demonstrated in service.

Interviews with helicopter and cargo handling component industries personnel were also conducted as stipulated by Task II. Cargo handling component subcontractors interviewed were:

- Mr. R. Walsh, The Breeze Corp., Union, N. J.
- Mr. L. Stivitts, Bergen Wire Rope Co., Lodi, N. J.
- Mr. R. Huber, Eastern Rotorcraft Corp., Doylestown, Pa.

The interviews and inspections of the subcontractors' facilities offered ideas for alternative approaches to cargo handling system qualification testing from that presently used. One concept presented by a subcontractor (also found in the literature reviewed) was that of the tumble-box for rough handling testing of components. The interviews were also useful in establishing the limits of the present state of the art of component testing. Particularly useful information was gained on the abilities and limitations of nondestructive testing of wire rope and nonmetallic slings.

Interviews with Sikorsky Aircraft pilots, engineers, and mechanics with experience in Southeast Asia and in the construction and lumber industries were conducted. Observations included verification that many service failures were the result of combined causes which had not been anticipated during component qualification testing. It was noted that many component rough-handling tests were not nearly severe enough to accurately predict component reliability in the field.

#### Task III and Task IV - Data Evaluation and Recommendations

As part of these tasks, the data and opinions accumulated in Task II were analyzed to discover deficiencies in current VTOL cargo handling system qualification practices. On the basis of comparing test methods, test performance, and field reliability, the following conclusions were reached:

Present qualification test methods do not assure reliability against failures with multiple causes. The need for combined endurance/environmental resistance test for cargo handling systems and components is indicated if assurance of consistent reliability for these items is to be achieved.

Present qualification test methods lack the statistical rigor required to accurately demonstrate reliability. If system reliability in the field is to be accurately predicted on the basis of test results, then statistical methods, as outlined in Section 1.2, must be applied.

It is recognized that the application of the recommendations included in this report will substantially increase cargo handling system qualification test costs due to requirements for increased length tests and more elaborate test facilities. However, these costs can be offset by a more substantial reduction in material losses due to assured cargo handling system reliability. The losses so reduced would include:

- material damaged or destroyed while being transported by the VTOL aircraft
- maintenance costs associated with repairing unreliable cargo handling systems and components
- operating costs of the extra flights required to complete a mission aborted due to cargo handling system failure.

The increased cost of a high-quality reliability assurance program must also be considered against reducing the probability of the consequences of a cargo-handling-system-caused logistics problem in a critical military situation, the cost of which may be incalculable. An analysis of the direct costs and benefits of these programs is included in the Trade-Off Study Section.

The final major conclusion reached in this study is that if present cargo handling system qualification test techniques are modified to include assurance against combined and cascaded failure modes and a more statistically rigorous demonstration of reliability, then the reliability of these systems will be significantly improved.

A

Works Reviewed								
	Oper- ational	Abusive	Proof Load	Ultimate Load	Endur- ance			St D
						Temp.	Temp Shock	
MIL-SPECS & MIL-STDS								
MIL-T-781B Terminal, Wire Rope, Swaging			X					
MIL-STD-810B Environmental Test Methods						X	X	
Environmental Testing, Aeronautical MIL-E-5272 & Associated Equip., General Spec For						X	X	
Hyd. Systems, A/C Types 1 & 11, MIL-H-5440E Requirements for								
Pneumatic Systems, A/C MIL-P-5518C Requirements For			X	X				
Containers, Shipping and Storage, MIL-C-5584C Metal Reusable								
MIL-S-5944 Slings, A/C, General Spec. For			X					
MIL-P-7034B Pulleys, Groove, Aircraft	X		X			X		
MIL-A-8421C Air Transportation Requirements General Spec. For								
MIL-T-8679 Test Requirements, Ground, Helicopter				X				
MIL-F-8905B Fittings & Cargo Rings, Tie-Down, A/C Floor			X	X				
MIL-D-23615A Design and Evaluation of Cartridge Actuated Devices						X		
MIL-H-81014A Hook, Helicopter Ext. Cargo, 20,000-lb Capacity	X		X		X	X		
MIL-H-81529 Hook, Helicopter Ext. Cargo, 6,000-lb Capacity, Type A	X		X		X	X		
MIL-W-83140 Wire Rope, ..., For A/C Rescue Hoist & Cargo Handling			X	X	X			

TABLE VI. TEST SPECIFICATIONS REVIEWED

[illegible]

C

						Comments
ce	Vib.	Shock	Alt.	Sun	Immer.	
	X	X	X	X	X	Used as basis for most environmental tests
	X	X	X	X	X	Alternate basis for many environmental tests
		X				
						Component level test requirements specified
						Contains inspection methods for containers
	X					
						Contains several useful specialized methods for testing pulleys
						Contains inspection methods for containers
						Specifies structural requirements for hard points
X	X	X	X		X	Methods for destructive testing included
	X	X	X		X	
	X	X	X		X	
						Contributed idea for test facility

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Works Reviewed							
	Oper- ational	Abusive	Proof Load	Ultimate Load	Endur- ance		
						Temp.	Temp Shock
Sikorsky Engineering Reports							
SER-60005 Detail Spec, Cargo Hoist 12,000-lb Capacity	X		X		X	X	
SER-60007 Detail Spec, Cargo Hook 12,000-lb Capacity	X		X		X	X	
SER-64099 Detail Spec, Cargo Hook 20,000-lb Capacity	X		X		X	X	
SER-64161 Detail Spec, Cargo Hoist 15,000-lb Capacity	X			X		X	
SER-64293 Detail Spec, Cargo Hook 25,000-lb Capacity	X		X		X	X	
SER-64294 Detail Spec, Cargo Hoist 25,000-lb Capacity	X			X	X	X	
SER-64325 Static Limit Load Test Cargo Lashing Reel Installation			X				
SER-64346 Qualification Test, Helicopter 25,000-lb Capacity Cargo Hoist							
SER-64349 4-Point Cargo Handling System Operating & Endurance Test	X				X		
SER-64497 Static Proof Test, Cargo Hoist Assy			X				
SER-64544 Detail Spec, Helicopter 4-Point Suspension System	X			X	X	X	
SER-64545 Detail Spec, Cargo Lashing Reel			X		X	X	

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TABLE VI - Continued

Applicability

of d	Ultimate Load	Endur- ance	Environmental Tests									
			Temp.	Temp Shock	Sand & Dust	Salt Spray	Humidity	Rain	Fungus	Ice	Vib	Shock
X		X	X		X	X	X	X			X	
X		X	X		X	X	X	X			X	X
X		X	X		X	X	X	X			X	X
	X		X		X		X					
X		X	X		X	X						X
	X	X	X		X	X			X			
X												
		X										
X												
	X	X	X		X	X	X					
X		X	X		X	X	X		X			

C

Tests							Comments
Angus	Ice	Vib	Shock	Alt	Sun	Inner	
		X		X			
		X	X	X		X	
		X	X	X		X	
				X			Contains component test specifications and test results
			X	X		X	which were compared with field R&M data for the same
X							components
				X			
X				X			

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Works Reviewed								
	Oper- ational	Abusive	Proof Load	Ultimate Load	Endur- ance			
						Temp.	Temp Shock	Sa Du
Sikorsky Aircraft Dwgs								
S6143-10105 RH3A MCM Winch	X				X			
S6152-62360 Rescue Hoist	X			X		X		
S6152-62366								
S6435-63090 Hoist Cable	X		X	X		X		
S6485-64500 Decoupler				X		X	X	
S65375-04500 Cargo Hook, 20,000 lb			X	X				
S65380-03100 Cargo Winch	X					X		
Other Documents								
FAR Part 29 FAA Airworthiness Standards			X					
FAR Part 133 External Cargo Handling Standards			X					
MHS.1-1970 Requirements for Containers American Nat'l Standards Test		X	X					

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TABLE VI - Continued

Applicability

Proof Load	Ultimate Load	Endurance	Environmental Tests									
			Temp.	Temp Shock	Sand & Dust	Salt Spray	Humidity	Rain	Fungus	Ice	Vib	Shock
		X				X						
	X		X		X	X	X	X				
X	X		X		X	X	X					
	X		X	X	X	X	X	X	X		X	
X	X											
			X									
X												
X												
X												

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C

						Comments
Ice	Vib	Shock	Alt	Sun	Immer	
			X			
			X			Specifies system level tests
					X	
	X		X		X	Specified system level test requirements
						Specifies performance and structural test requirements
						Design requirements for life & environmental resistance included
						Contributed to container structural tests